PEDESTRIAN TRANSPORTATION PROJECT PRIORITIZATION INCORPORATING APP-COLLECTED SIDEWALK DATA

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PEDESTRIAN TRANSPORTATION PROJECT PRIORITIZATION INCORPORATING APP-COLLECTED SIDEWALK DATA

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DEDICATION

To the memory of my mother, Marta Mellinger

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LIST OF SYMBOLS AND ABBREVIATIONS

§	Chapter in a legal document
AASHTO	American Association of Highway Transportation Officials
ABM	Activity-Based Model
ADA	Americans with Disabilities Act
ADAAG	ADA Accessibility Guidelines
ARC	Atlanta Regional Commission
CT-RAMP	Coordinated Travel and Regional Modeling Platform
DOT	Department of Transportation
GDOT	Georgia Department of Transportation
GIS	Geographic Information Systems
GPS	Global Positioning Systems
IMI	Irvine Minnesota Inventory
LOS	Level of Service
MARTA	Metropolitan Atlanta Rapid Transit Authority
MPO	Metropolitan Planning Organization

NJDOT	New Jersey Department of Transportation
NJTPA	New Jersey Transportation Planning Authority
NPU	Neighborhood Planning Unit
PEDS	Pedestrians Educating Drivers for Safety
PDA	Personal Device Assistant
PDI	Pedestrian Deficiency Index
PPI	Pedestrian Potential Index
PROWAG	Proposed Right-of-Way Accessibility Guidelines
RCLINK	Identification code for GDOT roadway characteristics database
SPI	Special Public Interest zoning district
SPSS	Statistical Product and Service Solutions

SUMMARY

Planners and decision-makers recognize that non-motorized transportation provides environmental, economic, and public health benefits. Recent technology advances, such as the widespread use of mobile devices and geographic information systems, enable the collection of disaggregate built environment and travel behavior data. To integrate pedestrian planning into transport operations at local and regional scales, it is necessary to develop systems to rank and prioritize zones and corridors for pedestrian infrastructure investment. Best practices for pedestrian planning suggest that jurisdictions prioritize pedestrian projects based on a variety of concerns, such as high pedestrian activity, pedestrian safety, accessibility to transit and mobility for persons with disabilities, children and older adults. Researchers at the Georgia Institute of Technology developed and piloted an automated system to assess the quality of sidewalks, utilizing an Android™ App that collects GPS-enabled video, accelerometer, and gyroscope data. Researchers collected pilot sidewalk data within the City of Atlanta to evaluate the accessibility and walkability of pedestrian facilities.

This research proposes a weighted ranking system to prioritize pedestrian projects using App-collected pedestrian facility data collected in the field using a mobile Android application, pedestrian safety indicators, pedestrian activity data and demographic data. The ranking system uses a set of block-level pedestrian potential and deficiency indicators to prioritize planning investments within a subarea of Midtown, Atlanta, Georgia, combining available data sources with app-collected sidewalk width data. The results of these rank-order prioritization analyses indicate that blocks near rail stations and Georgia Institute of Technology/Technology Square should be prioritized for pedestrian investments. However, further refinements are needed to

extend the application of this methodology to larger geographic scales. Additionally, this research did not consider the cost constraints of pedestrian project alternatives within the study area. Future availability of comprehensive pedestrian activity and pedestrian network data will enable planners and engineers to prioritize corridors and intersections for pedestrian project implementation.

CHAPTER 1

INTRODUCTION AND RESEARCH OBJECTIVE

1.1 Introduction

Planners and decision-makers recognize that non-motorized transportation can provide substantial environmental, economic and public health benefits. Efforts to encourage non-motorized transportation often emphasize the negative impacts of the automobile-centric transportation infrastructure and land use development, including increased air emissions, reduced physical activity, and higher economic costs of traffic congestion. Additionally, non-motorized transportation is critical in providing accessibility and personal mobility for non-automobile owners, transit riders, persons with disabilities, and older adults.

Sidewalks are an integral part of sustainable transportation systems, supporting pedestrian travel and healthy physical activity. Presence and quality of sidewalks has been found to be a significant predictor of perceived safety and quality of the pedestrian environment (Landis et al. 2005). In a recent study of mode choice and street network characteristics in 24 California cities, street features such as on-street parking, bike lanes, and sidewalk presence were associated with less driving (Marshall & Garrick, 2010). Mode shifts to walking and other non-motorized forms of transportation are associated with increases in physical activity and improved health, (Woodcock et al., 2009) and may lead to decreases in vehicle miles traveled and roadway congestion (Frank et al., 2006). However, a sensitivity analysis indicates that the interpretation of the significance of built environment variables may differ depending on the model formulations, variable specifications, and the objects or entities that are analyzed (Bodea et al., 2008). The authors recommend that future research incorporate non-linear relationships and account for self-selection bias to improve the sensitivity of models testing the associations between physical activity measures and built environment characteristics.

Sidewalks were recognized by the Americans with Disabilities Act as a vital part of accessible transportation infrastructure to improve quality of life for persons with disabilities. Pedestrian facility assessment is necessary to comply with the Americans with Disabilities Act, as local agencies were required to develop ADA Transition Plans and may be legally responsible for negligent infrastructure maintenance. The lack of pedestrian facility data has been nationally recognized as a major barrier to ADA compliance (U.S. Government Accountability Office, 2007).

Additionally, sidewalk condition is one of several pedestrian-scale data sources needed to accurately plan for pedestrian facilities and prioritize new infrastructure. Recent research has tested the relationship between perceived walkability and sidewalk quality; however few studies have assessed pedestrian facility condition using quantitative data. On a regional and national scale, the need for pedestrian-scale data has also presented a barrier to robust pedestrian transportation modeling. This gap identifies the need for improved data collection, data quality, and objective evaluation systems to inform pedestrian project prioritization.

Although studies and practitioners recognize the benefits of providing high-quality pedestrian infrastructure for accessibility, safety, and quality of life, gathering sidewalk-level data remains a challenge. In recent years, emerging technologies such as mobile apps, geographic information systems (GIS), and crowdsourcing have supported efforts of researchers and practitioners to automate process of data collection, improve accuracy, cost-effectiveness. To develop an automated and cost-effective process for assessing sidewalk quality, researchers at the Georgia Institute of Technology developed and deployed an Android tablet application to automatically assess sidewalk quality and generate spatial sidewalk inventories to be used in pedestrian prioritization and planning.

1.2 Research Objective

The objective of this research is to develop and test a methodology to incorporate app-collected sidewalk data with other available data sources to prioritize pedestrian projects. In addition to average sidewalk width data from the Georgia Tech app, the external datasets used included demographic and mode share data, pedestrian crash data and pedestrian activity data. As the ability and technology to collect and employ pedestrian-scale data improves, methodologies are needed to prioritize pedestrian projects at various scales.

This research demonstrates an approach that integrates objective pedestrian-scale infrastructure data into planning and prioritization systems, helping to address the current lack of quantitative data within pedestrian planning data and methods. This approach could be replicated in jurisdictions nationally using the Georgia Tech sidewalk assessment system and other locally available data sources. Therefore, this research approach and methodology is transferable to local, regional and state jurisdictions and could incorporate additional data sources and sidewalk quality data as it becomes available.

CHAPTER 2

RESEARCH BACKGROUND

2.1 Pedestrian Assessment and Prioritization Methods

Within recent research and practice, approaches to prioritize pedestrian projects incorporate federal accessibility guidelines, new technologies for data collection, and research linking built environment characteristics to walkability, pedestrian safety, and non-motorized travel demand. Federal, state, and local guidelines recommend that safe and accessible pedestrian infrastructure incorporate elements such as passable slopes, sufficient sidewalk widths, and smooth walking surfaces. Additionally, recent studies suggest that parameters such as sidewalk presence and buffer from vehicular traffic may predict walkability, sense of security, and convenience of the pedestrian environment. Although methodologies for sidewalk inventory and assessment are emerging, local agencies have utilized GIS-based surveys, level-of-service models, and other techniques to support pedestrian planning, regulatory compliance, and asset management.

2.1.1 Pedestrian Accessibility Guidelines

The Americans with Disabilities Act (1990) established transportation access to public facilities and buildings as a civil right, including access to public transportation. In terms of pedestrian infrastructure standards, The Americans with Disabilities Act provides clear design specifications to bring infrastructure into compliance. The aim of ADA design standards is to enable safe transportation for disabled persons to public facilities. ADA-compliant infrastructure also promotes safety, mobility, and accessibility for all users. Although the ADA Accessibility

Guidelines (ADAAG) did not specifically address sidewalks, standards relating to "accessible routes" and curb ramps are applicable to the pedestrian environment (U.S. Access Board, 2002; U.S. Access Board, 2011). For example, ADAAG requires specific widths, surface conditions, grade and cross-slope for "accessible routes" (Quiroga & Turner, 2008, U.S. Access Board, 2002; see Table 1).

Table 1: ADA Design Guidelines, Public Right-of-Way

Design Feature	Federal Guidance
Clear Sidewalk Width	36 inches minimum
	If less than 60 inches, provide passing space every 200 feet
Running Slope	5% maximum or equal to roadway slope
Cross-Slope	2% maximum
Obstructions	None within pedestrian access route
Pavement material	Firm, stable and slip-resistant
Changes in Level	Vertical changes up to 1/4 inch allowed without edge treatment
Vertical Clearance	80 inches minimum
Curb Ramp Width	36 inches minimum

Subsequent federal regulations and design guidelines published by the U.S. Access Board have given guidance for the implementation of ADA requirements for design and alteration of accessible public facilities and programs. According to these regulations, all new construction and "major alterations" must comply with ADA accessibility design guidelines. Further, regulations did not require that facilities constructed prior to 1992 be retrofitted to comply with accessibility guidelines. However, jurisdictions were required to develop ADA transition plan and self-evaluation by January 26, 1992 which details a plan to update existing facilities in the future to ensure accessibility for persons with disabilities (Title II of the Americans with Disabilities Act, 1990).

Pedestrian infrastructure is legally considered part of the "public right of way" and local governments are liable for physical injury resulting from negligent maintenance of infrastructure (see Prystowsky, 2010). Recent case law established that sidewalks are included in ADA requirements, municipalities are responsible for removing barriers to reasonable accessibility, and expanded the definition of roadway "alterations" to include maintenance projects (Barden v. Sacramento, 2002). The issue of sidewalk maintenance has been addressed in recent case law, in which plaintiffs sought injunctive relief under Title II of ADA and argued that pedestrian facilities be considered a public service or program administered by governments (Lautt, 2011). Title II of ADA ensured reasonable accommodation to all government services and programs, and subsequent regulation expanded the scope to include all activities of state and local governments.

In 2002, The U.S. Access Board published a design guide addressing accessibility in pedestrian design (Proposed Accessibility Guidelines, 2011). A major issue in pedestrian infrastructure design is the appropriate sidewalk corridor width. The proposed accessible right-of-way guidelines (PROWAG) require a minimum "continuous clear width" to allow sufficient space for persons with disabilities to travel. To assess pedestrian infrastructure conditions, it is also important to assess slope and pavement quality. According to proposed guidelines, the running slope of pedestrian access routes should not exceed the slope of the adjacent roadway and should be 5% maximum at pedestrian crossings. Additionally, the Access Board's design guide identified cross-slopes greater than 2% as a barrier to accessibility. Appropriate cross-slope is an access issue both on the sidewalk environment and at driveway crossings (Proposed Accessibility Guidelines, 2011).

Design guidelines for accessible pedestrian infrastructure recommend minimum clear width and clear length at transit boarding areas, as well as a "level and stable" surface at the boarding area. Generally, sidewalk pavement should be "stable, firm and slip-resistant," and certain construction materials are not recommended for safety reasons. Design guidelines also specify maximum changes in level to ensure a continuous path of travel (Proposed Accessibility Guidelines, 2011). Accessibility design guidelines and technical specifications provide a framework for assessing pedestrian conditions.

Traditional sidewalk data collection methods require significant time and resources for public works departments. However, new methods are emerging to streamline the sidewalk assessment process and aid municipalities in developing their ADA transition plans and planning for pedestrian facilities. Volunteer labor, automated data collection systems, and GIS technologies have been utilized by state agencies in order to streamline pedestrian and ADA data collection processes (Quiroga & Turner, 2008). As an example, The City of Bellevue estimated that the inertial profiler system for ADA inventory would realize 70% savings when compared with the estimated cost of a traditional, manual sidewalk inventory (Khambatta & Loewenherz, 2011).

2.1.2 Pedestrian Quality-of-Service Indices

The motor vehicle "Level of Service" transportation planning tool has been used to assess the available roadway capacity available to satisfy current and projected vehicle travel demand. However it has been noted that in additional to the provision of pedestrian facilities, environmental and individual factors play a role in influencing demand for non-motorized modes (Pratt, Evans & Levinson, 2012; Moudon et al., 2002). Thus, researchers and practitioners have developed evaluation and planning tools to assess the suitability of facilities and corridors for pedestrian improvements, including variables such as pedestrian comfort, accessibility to facilities and infrastructure condition. Although many of these models utilize the term "level of service," a distinction should be made between capacity-based vehicle level of service methods and pedestrian suitability or comfort-based pedestrian LOS models and indices. For example, Landis et al. proposed a pedestrian LOS model based on built environment variables correlated with pedestrian response to identify factors important for pedestrian comfort and walkability (2005). The authors selected several primary factors to include in the pedestrian LOS model, including lateral separation from traffic (sidewalk presence), traffic speed, traffic volume, and driveway access points.

Recent studies have identified sidewalk width, presence and buffering/amenities as predictors of pedestrian travel, perceived safety and quality of the pedestrian environment (Marshall & Garrick 2010; Landis et al. 2005; Kockelman et al. 2001). In an index based on perceived importance to wheelchair users, effective sidewalk width, pavement condition and material were found to be important variables for sidewalk accessibility (Ferreira & da Penha Sanches, 2008). Additionally, a review of 25 pedestrian indices found that objective variables for measuring walkability included sidewalk width, presence, slope and presence of a buffer (Meghelal & Capp, 2011).

In developing pedestrian indices, several studies incorporated survey data or objective built environment measures to assess the relationship between perceived pedestrian comfort or quality of service and the physical condition of the pedestrian environment. For example, Boarnet et al. analyzed the relationship between built environment variables and walking and physical activity behavior using the Irving Minnesota Inventory (2011). The IMI is a built environment audit tool, based on in-person field observations of variables that contribute to environments supporting walking, including density, street network, presence of mixed-use development, pedestrian infrastructure, and social and economic variables. This study utilized physical activity, obesity and socioeconomic data corresponding to its 716 research subjects. In addition, the researchers utilized the IMI to survey the built environment characteristics near the study subjects' residences. Based on the results of this study, the authors concluded that the indicators most associated with walking measured the presence of destinations, traffic, and presence of sidewalks (Boarnet et al., 2011).

A growing body of public health research evaluates the relationship between physical activity and the built environment to aid in obesity prevention. According to a review of the "first generation" of built environment audit tools to measure physical activity (Brownson et al., 2009), studies utilize interview and/or survey data, in-person environmental audits or available GIS datasets to analyze built environment data. The authors noted that the use of observational measures tends to be time-consuming and require prior knowledge of built environment design features. Additionally, Brownson notes that training and monitoring can be used to address inter-rater reliability issues when a research study uses observational measures.

Of the 50 GIS-based studies reviewed, five included a "sidewalk coverage" variable in its analysis, and the authors indicate that pedestrian infrastructure data are often lacking from local, electronic databases. The most common GIS-based measures include population and intersection density, land-use mix, sidewalk presence and traffic characteristics. According to Brownson and co-authors, one methodological challenge in using GIS datasets is the dearth of research testing the extent and effect of inaccurate or incomplete data (i.e. by comparing field results with existing datasets). Additionally, the authors stated that the differing environmental variable specifications made it difficult to test reliability of GIS measures across multiple studies. Chapter 5 further discusses methodological challenges in the application of GIS measures within this analysis.

2.1.3 Pedestrian Infrastructure Prioritization: State of the Practice

Within transportation planning and engineering practice, methods and "best practices" for pedestrian transportation data and prioritization are emerging. In 1994, the City of Portland developed two indices to prioritize pedestrian projects, the Pedestrian Potential Index and the Pedestrian Deficiency Index (Schwartz et al., 1999). The PPI consisted of three factors (designation of urban activity centers, pedestrian activity variables and proximity to pedestrian generators), while the PDI included variables such as sidewalk presence, street connectivity and traffic characteristics. The City of Portland utilized ArcMap to score pedestrian projects based on their current pedestrian deficiencies and potential for pedestrian activity. As a proxy for pedestrian demand, the original model utilized short (2 miles or less) trip data from the regional travel demand model. Combined with community and cost-effectiveness input, projects were ranked highly if they scored high on both the PDI and PPI indices (Schwartz et al., 1999). This methodological approach was subsequently used in multiple pedestrian prioritization studies.

Applying Portland's potential and deficiency indices, a study tested methods to prioritize pedestrian investments in suburban areas in the Seattle metropolitan area (Moudon et al., 2002). Demonstrating two approaches to pedestrian prioritization tools, Moudon and co-authors utilized census-block level and parcel-level land use and density data to identify clusters of latent pedestrian demand. However, the authors noted that future research will require additional transportation infrastructure and travel behavior data to link transportation and land use considerations in pedestrian prioritization.

Two recent studies detail the pedestrian prioritization methods utilized at a regional scale by the North Jersey Transportation Planning Authority (Matley et al., 2000; Swords et al., 2004). In preparation of its comprehensive transportation plan, the NJTPA developed a PPI theoretical framework that conceptualized pedestrian travel demand as the link between "proximity" and "connectivity" (Matley et al., 2000). Thus, PPI indicators might include variables related to land use, density, urban design, and sidewalk network extent. In the case of the NJTPA index, the variables selected included land use mix, and employment, population and street network densities at the census tract scale (given the broad geographic scope of the MPO). Although recognized as a key element in pedestrian travel demand, data on sidewalk availability was not available at a regional scale.

To update the statewide bicycle and pedestrian master plan, New Jersey DOT identified priorities for transportation investment based on both transportation demand and infrastructure "supply" (Swords et al., 2004). The intent of this update was to provide an analytical framework for selecting priority corridors for bicycle and pedestrian projects. Similar to Portland's PPI index method, areas were prioritized that scored high on the potential demand analysis and low on the existing infrastructure analysis.

NJDOT analysts did not assess current conditions and existing transportation demand due to the lack of sidewalk inventory and pedestrian trip data. However, NJDOT developed an approach to assess the "barrier severity" of crossing a roadway, based on roadway characteristic data and a calculation of available gaps in traffic. NJDOT analysts estimated pedestrian demand based on a combination of population and employment data with a transit accessibility measure. More detailed information on the estimation of the statewide pedestrian demand index was not publicly available. Land-use data was not utilized in this study because it was not available on a statewide basis. The results of this combined supply/demand analyses indicated that 55% of roadway miles should be prioritized for pedestrian projects, largely in urban and suburban areas in New Jersey (Swords et al., 2004).

2.1.4 Improving Pedestrian Data through Technological Advances

As noted in the previous section, both researchers and practitioners often lack pedestrian facility data, to assess existing conditions and prioritize improvements. In addition, the dearth of local, regional and statewide pedestrian facility data has been a barrier to assessing and enforcing ADA compliance (US Government Accountability Office, 2007) as well as the development of regional transportation models incorporating non-motorized trips (Pratt, Evans & Levinson, 2012).

Traditional methods of sidewalk inventory are often time and cost-prohibitive, particularly for large-scale implementation. A literature review of 29 jurisdictions' pedestrian and bicycle data collection initiatives found a variety of methodologies used, including user surveys, to facility inventory and spatial analysis (Schneider, Patten & Toole, 2005). Among these 29 case studies reviewed, 13 included a pedestrian facility inventory element. According to these case studies, bicycle and pedestrian data collection can provide evidence of changing travel patterns, identify locations for infrastructure improvements, evaluate new infrastructure needs, and can also be used for bicycle and pedestrian planning.

Researchers have recognized the tension within non-motorized transportation research between utilizing automated data and detailed in-person audit instruments (Boarnet et al., 2011). According to Boarnet et al., Comprehensive built-environment inventory tools can provide detailed pedestrian-scale data, but may require substantial staff time and cost needed to inventory a large number of detailed built-environment variables over a large area (2011).

Additionally, the use of audit or survey data introduces potential validity and reliability concerns, as many inventory tools use subjective scales to measure infrastructure condition (i.e., "poor," "fair" and "good" sidewalk quality). Few studies have tested the validity and reliability of built environment audit instruments. However, the Irvine Minnesota Inventory audit instrument results were analyzed to test both predictive validity and inter-rater reliability (Boarnet et al., 2006; 2011). During reliability testing of the Irvine Minnesota Index, audits were conducted in Minnesota and California with multiple raters in several audit sites. Most audit parameters had high reliability; with higher reliability in the Minnesota tests when compared with the California reliability tests (76.2% compared with 99.2% of variables had greater than 80% agreement). Additionally, the authors noted that raters in both locations found it necessary to sample block segments due to the time-consuming nature of the audit instrument (Boarnet et al., 2006).

However, emerging technologies such as mobile devices and applications enable the collection of non-motorized infrastructure and travel behavior data without the use of costly and time-consuming built environment surveys. A review of ADA compliance efforts at state departments of transportation details the growing use of technology to make pedestrian data collection more cost-effective and to improve data quality (Quiroga & Turner, 2008). Based on interviews with agency staff, best practices for cost-effective data collection include the use of volunteer labor, GIS-based data collection, and database integration.

Several agencies incorporated sidewalk inventory into their annual paper-based roadway inventory procedure and later digitized these data into GIS or other database systems. For example, Oregon DOT conducts both sidewalk and roadway inventory using manual data entry from video logs. New technologies such as GIS-enabled devices have been utilized to improve the efficiency and database integration of built environment inventories. For example, University of Oregon researchers collected data on sidewalk width and condition using GPS-enabled personal device assistant (PDA) units (Schlossberg et al., 2008). This audit tool was utilized by Oregon DOT to supplement their sidewalk inventory data with digitized curb ramp field data.

In cooperation with the Federal Highway Administration, the city of Bellevue, Washington completed a sidewalk and curb ramp inventory for its ADA transition plan (Quiroga & Turner, 2008). The City of Bellevue found traditional inventory methods to be prohibitively costly, and piloted a prototype inertial profiler system for data collection to realize 70% cost savings (City of Bellevue, 2009). The City of Bellevue used a Segway™ human transporter equipped with an inertial profiler and personal computer for GIS integration to collect data on sidewalk and curb ramp condition. The City conducted a ranking analysis to prioritize non-compliant infrastructure features for repair. The ranking analysis calculated activity and impedance factors based on demographic, transportation, and land use data as well as inventory results (City of Bellevue, 2009). Table 2 shows the detailed indicators included in the City of Bellevue activity and impedance scores used in the ADA barrier ranking analysis. According to the ADA Self-Evaluation Report, “narrow sidewalks” was included within the sidewalk obstructions indicator. Currently, four other cities plan to utilize inertial profiling systems for

ADA compliance inventory: The County of St. Louis, Missouri, and San Carlos, Clovis, and San Marcos, California (Khambatta & Loewenherz, 2011).

Table 2: Accessibility Indicators Included in City of Bellevue Barrier Ranking Analysis

Index	**Indicator**
Activity Score	Proximity to households with disabilities
	Traffic volume
	Proximity to places of public accommodation
	Housing density
	More than 6% Population Older Adults
	In Major Employment Center
	Proximity to Parks
	Proximity to Schools
	Proximity to Retail
Impedance Score	Density of Fixed Obstructions
	Density of Changes in Level Violations
	Density of Cross Slope Violations
	Density of Grade Violations
	Presence of Ramp Obstructions
	Alignment with Marked Crosswalks
	Presence of Detectable Warning Surface
	Presence of Smooth Ramp Transition
	Size of Curb Ramp Landing
	Curb Ramp Landing Slope
	Curb Ramp Width
	Curb Ramp Flare Slope
	Curb Ramp Panel Grade
	Curb Ramp Panel Cross-Slope
	Gutter Grade
	Gutter Cross Slope

In recent years, mobile devices have been utilized to automate the process of data collection and to collect infrastructure and travel behavior data using built-in sensors. The use of mobile phone data, particularly location capabilities, has a wide range of intelligent transportation systems applications, such as automatic vehicle location systems in public transit (Zhao, 2000). Mobile data collection has also been utilized within non-motorized transportation planning and research to track transportation activity. For example, researchers at Georgia Tech, in collaboration with the City of Atlanta and other partners, piloted an app to monitor the travel behavior of bicyclists within the city (Misra et al., forthcoming). The data from this crowd-sourced app, Cycle Atlanta, is to be used to assess existing bicycle transportation travel patterns and to guide future planning and project implementation. In addition to GPS capabilities, video data from mobile devices has been used to detect and track vehicles and pedestrians (Zhang et al., 2011). Image processing techniques and inertial profiling systems have been utilized to monitor roadway condition, including crack detection integrated with GIS software (Chung et al., 2004).

A review of best practices in pedestrian infrastructure planning demonstrates the potential of emerging technologies for accurate and cost-effective asset management. Quantitative inventories of sidewalk and curb ramp infrastructure assist in ADA compliance efforts, municipal repair prioritization to increase safety and walkability. However, current gaps in literature and practice indicate a need for development of a replicable, objective, cost-effective system to assess pedestrian infrastructure quality and prioritize future pedestrian projects on local, regional and statewide scales.

2.2 Georgia Tech Sidewalk Assessment System

To address the current research gaps in pedestrian data collection and evaluation, researchers at the Georgia Institute of Technology developed an automated system to assess the condition and quality of sidewalks. Researchers developed an Android™ app, Sidewalk Sentry™, which automatically records video and collects GPS, accelerometer and gyroscope data (Frackelton et al., 2013). When attached to a basic manual wheelchair, a tablet collects data that is used to evaluate where sidewalks may be in need of repair or reconstruction based on ADA accessibility guidelines (see Figure 1). These data include high-resolution video, gyroscope and accelerometer readings, GPS coordinates and second-by-second timestamp as well as ephemeris data. In order to record data using the Sidewalk Sentry™ app, the user needs to first obtain a GPS location "fix" and then press "record." Sidewalk data is collected on both sides of the street using predetermined routes.

Figure 1: Sidewalk Data Collection System Setup

The research team tested and calibrated the data collection system using Toshiba Thrive tablets attached to a manual wheelchair using Velcro straps, mounts and a high-density polyethylene board (Grossman et al., 2013). Using volunteer and student labor, the research team began large-scale deployment in early 2013 throughout the City of Atlanta. Figure 2 shows a map of the GPS data collected as of October 2013. The research team prioritized data collection within the urban core areas (defined as inward from the BeltLine overlay district), the Midtown, Downtown and Buckhead Community Improvement Districts, and a half-mile buffer around MARTA rail stations within the city boundaries. This prioritized area consists of approximately 659 roadway miles, 12,089 intersections and contains 3,489 Census blocks.

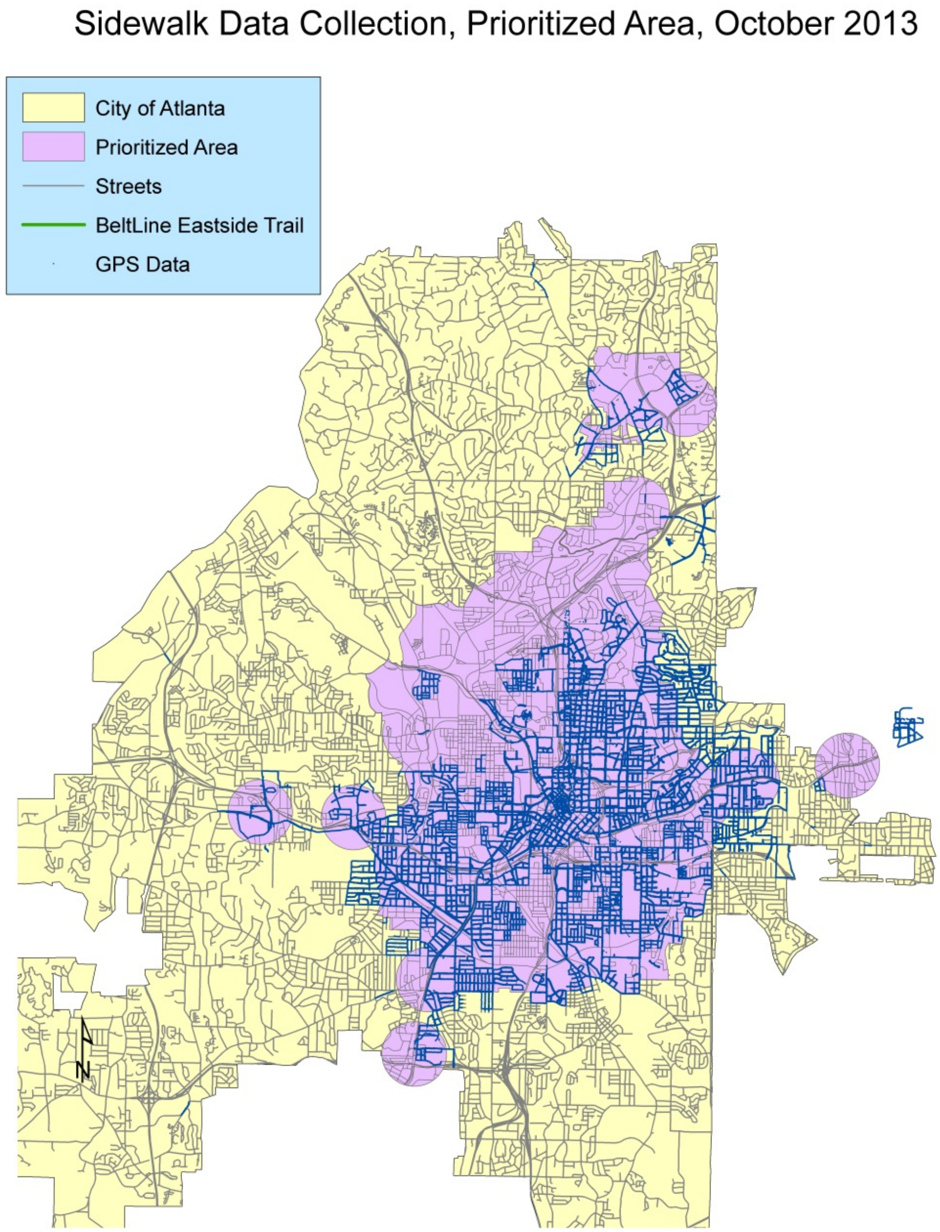

Figure 2: Sidewalk Data Collection Research Progress, October 2013

The research team engaged stakeholders and decision-makers throughout the project to aid future implementation of the sidewalk quality assessment system to improve pedestrian facility planning and asset management on a local, regional and state level. The research team consulted with the Georgia Department of Transportation staff, City of Atlanta planning and engineering staff, the Atlanta Regional Commission and PEDS (Pedestrians Educating Drivers for Safety) on sidewalk quality indicators and data collection priorities. The research team also obtained information regarding existing sidewalk assessment processes at the local and regional scales. In September 2012, the research team conducted kickoff meetings with key staff members at the City of Atlanta Department of Public Works, who were very interested in the potential of this research to improve sidewalk inspection and maintenance prioritization within the City of Atlanta (R. Mendoza, September 4, 2012, personal communication).

To improve the cost-effectiveness of field data collection, the research team employed undergraduate students as data collectors and coordinated several field deployments with community volunteers. The research team routinely presented at neighborhood planning unit (NPU) meetings and at local neighborhood association meetings to engage with local neighborhoods and generate interest in volunteering. The team presented a session at a transportation "un-Conference" attended by practitioners and stakeholders to solicit feedback on key sidewalk quality indicators.

Based on a review of ADA guidelines and walkability indicators, the researchers identified sidewalk width, surface roughness, pavement crack density, and presence of obstructions as key indicators of sidewalk quality (Frackelton et al., 2013). By detecting the presence of lines and edges within the video data, researchers' process field data to estimate the location of obstructions within the public right-of-way, detect the presence of cracks, and estimate the width and presence of sidewalks (see Figure 3; Palinginis & Guensler, forthcoming). Using GPS and timestamps of raw app data, researchers link sidewalk quality parameters to individual sidewalk segments and are thus able to evaluate sidewalk quality and display results to project sponsors and stakeholders.

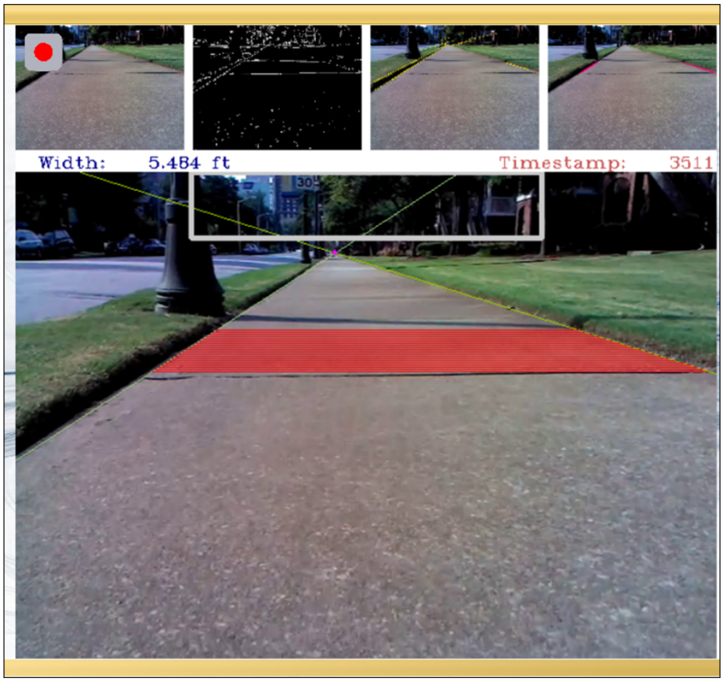

Figure 3: Sidewalk Width Video Processing Example Image

Project results will be presented to stakeholders and practitioners on an interactive website currently in development using the open-source Open Street Map interface. The website displays a map of collected data, which will be color-coded based on sidewalk quality evaluation results from field data post-processing. An example of the web interface in development is shown in Figure 4, which displays mapped sidewalk quality data and video data side by side. These results will be open to the public; while more advanced users (such as agency staff) will be able to view rolling video data and more detailed sidewalk quality data, such as width measurements and the presence of obstructions. Thus, agency staff will be able to respond to public input and view field-verified infrastructure condition before sending inspection crews out to address the issue. Thus, local, regional and state agencies will be able to utilize sidewalk quality ratings into ongoing and future pedestrian planning, project prioritization and implementation.

Figure 4: Sidewalk Sentry Mock-up Web Interface

2.3 Pedestrian Planning and Prioritization in the City of Atlanta

To implement a data-driven pedestrian prioritization system, it is important to coordinate with local planning initiatives and policy priorities. The City of Atlanta is currently in the process of implementing "Complete Streets" projects and policies supporting walkability. In selecting the relevant data sources and walkability indicators for prioritization in the City of Atlanta, it is important to consider existing plans, project selection criteria and existing conditions to streamline implementation.

2.3.1 Existing Conditions and Travel Behavior in the City of Atlanta

Despite the automobile-centric reputation of the Atlanta metropolitan area, 4.4% of Atlanta city residents walked to work, 0.8% of city residents biked to work and 11.6% commuted by transit (American Community Survey, 2011). The Federal Highway Administration has identified Atlanta as a Pedestrian Safety Focus City due to its relatively high rate of pedestrian fatalities (Redmon, et al., 2012).

The City of Atlanta estimates a total sidewalk network of approximately 2,158 miles (City of Atlanta, 2008a; City of Atlanta, 2010); however, the exact sidewalk network distance and state of good repair estimates are somewhat uncertain. The 2008 State of the City's Infrastructure report estimated that 18% of the sidewalk network to be deteriorated and assumed that 395 miles of sidewalk are defective. The City of Atlanta Public Works Department estimated that the pedestrian infrastructure repair backlog totals nearly $153 million, as shown in Table 3 (2008a).

Table 3: Sidewalk Inventory Backlog Estimate, City of Atlanta

	Total Inventory (miles)	**Estimation Rate**	**Backlog**	**Backlog Cost (unit cost $/mile)**	**Total Cost ($ million)**
Sidewalk	2,158	18.3%	395 miles	$118,800	$109.01
Curbing	2,158	10 %	216 miles	$132,000	$ 29.34
Incidentals	--	10%	--	--	$ 14.25
TOTAL					$ 152.60

The City of Atlanta has faced litigation from the U.S. Department of Justice under the Americans with Disabilities Act for non-compliant sidewalks and curb ramps (U.S. Department of Justice, 2009). As a provision of the settlement agreement with the Department of Justice, the City of Atlanta was expected to provide curb cuts and pedestrian walkways for all new construction and alterations within three months of December 2009. Pedestrian infrastructure is legally considered part of the “public right of way” and local governments can be liable for physical injury resulting from inadequate maintenance of infrastructure. Injury lawsuits related to deteriorated sidewalk facilities have cost the City of Atlanta millions of dollars in the last few years; which is substantially more than it would cost to repair a sidewalk. As shown in Table 3, the estimated unit cost per mile of sidewalk is $118,800. For example, the city negotiated a multimillion-dollar settlement in 2012 to resolve injury claims due to a sidewalk that would have cost $2,000 to repair (Diggs, 2012).

2.3.2 Pedestrian Planning Prioritization and Policy

These driving forces led the Atlanta City Council to convene a Sidewalk Task Force to research public policy issues associated with sidewalk maintenance, pedestrian facility funding, and pedestrian safety. The Sidewalk Task Force held several planning meetings in 2012, and presented recommendations to Atlanta City Council in May 2012. Several expert stakeholders, including staff at the City of Atlanta Office of Planning, Department of Public Works, and the Atlanta Regional Commission have noted the outstanding need for a comprehensive inventory of Atlanta’s pedestrian facilities prioritize repairs and future infrastructure (B. Rushing, May 20, 2013, personal communication; J. Mello, May 20, 2013, personal communication; R. Mendoza, September 4, 2012, personal communication; Flocks, 2013). The 2010 Transportation Infrastructure and Fleet Inventory Report estimated that a streets/sidewalk inventory and assessment would cost approximately $1.2 million, and this assessment was listed as a high priority for future studies conducted by the Department of Public Works (City of Atlanta, 2011). According to the Department of Public Works, functional classification, facility connectivity (schools, transit, parks, commercial centers), safety, and population density data should be used to prioritize sidewalk repairs and reconstruction (M. Wynn, February 6, 2012, personal communication).

As of the time of writing, the City of Atlanta has not released a stand-alone pedestrian master plan. In 2007, the City published its first comprehensive transportation plan, the Connect Atlanta Plan. The Connect Atlanta Plan focused on promoting transit ridership, walking, and bicycling to improve connectivity and livability within the urban core (City of Atlanta, 2008b). Additionally, the plan recommended specific transportation improvement projects within each sector of the city. The Connect Atlanta Plan included street and transit project concepts evaluated on the basis of several prioritization metrics, including reduction of vehicle-miles-traveled, promoting multi-modal options, and connectivity as well as pedestrian accessibility.

The Connect Atlanta Plan also included street design guidelines for projects within city right-of-way, with sidewalk width recommendations for each street design context (i.e., "high-density mixed-use boulevard," "commercial street," etc.). The City of Atlanta is currently in the process of developing detailed "Complete Streets" design guidelines to implement the policy goals and recommendations of the Connect Atlanta Plan. This draft design manual, entitled "Move Atlanta: A Design Manual for Active, Balanced and Complete Streets," was based on the Los Angeles County "Model Design Manual for Living Streets" and adapted to conform to state and national transportation design standards as well as city regulations.[1] The City of Atlanta

[1] The author was the primary author of the draft "Complete Streets" design manual for the City of Atlanta as a Transportation Planning Intern from May-August 2012.

plans to conduct a citywide bicycle study and a citywide pedestrian study to further the development and prioritization of active transportation projects (Mello and Jones, 2013).

In 2004, the Atlanta Regional Commission (ARC) conducted an inventory of pedestrian facility conditions near rail transit stations and key bus transfer stations. This inventory was completed using GIS-enabled PDA devices and included land use, sidewalk presence and condition, driveway accessibility, buffer and pedestrian crossing attributes (Atlanta Regional Commission, 2004a, 2004b). The ARC released its first bicycle and pedestrian plan in 2007. Major regional pedestrian planning goals were to provide accommodations to pedestrian LOS "B" within Livable Centers Initiative (LCI) areas and "Regional Places" and pedestrian LOS C on other roadways, prioritizing pedestrian improvements near schools, transit stations, and greenspace (Atlanta Regional Commission, 2007a).

The plan proposed a level of service model based on the work of Landis et al. (2005), which defined pedestrian "suitability" based on sidewalk presence, roadway width and traffic characteristics. Selected regionally significant roadways were evaluated based on these criteria. The ARC's regionally significant transportation system includes interstate highways, roadways serving existing and future transit service, and inter-county arterial roadways (Atlanta Regional Commission, 2007b) the 2007 bicycle and pedestrian plan identifies a prioritization scoring process for regional pedestrian planning. The plan calculated a pedestrian score as a function of pedestrian level-of-service, potential for walking activity, congestion (as measured by the Travel Time Index), project cost, and whether the project is located within a Station Community or Livable Centers Initiative site (Atlanta Regional Commission, 2007c).

The long-range regional transportation plan, Plan 2040, allocated $1.6 billion to bicycle and pedestrian infrastructure projects. Pedestrian project selection within Plan 2040 depended on conformity with regional planning goals and performance measures, such as the "bicycle and pedestrian network expansion" policy filter. Within the Transportation Improvement Program, pedestrian projects are typically funded under the Last Mile Connectivity and General Purpose Roadway Operations and Safety programs. For example, the installation of ADA-compliant sidewalks and pedestrian crossings is listed explicitly as an example project type within the Last Mile Connectivity program (Atlanta Regional Commission, 2013a).

In recent years, metropolitan planning organizations have incorporated non-motorized transportation into regional travel demand models to enhance the sensitivity of regional modeling and to reflect changes in development and travel behavior. According to a review of non-motorized transportation within regional travel demand models, a majority of large MPOs include non-motorized transportation in their models (Clifton and Singleton, 2011).

In addition to the historic trip-based model, the Atlanta Regional Commission is developing an activity-based model (ABM). Rather than using individual trips as the unit of analysis, the activity-based modeling approach focuses on travel as a function of demand for activities (Davidson et al., 2007). The Atlanta Regional Commission's ABM is based on the CT-RAMP platform of activity-based travel demand models. The major data inputs for the ABM include highway and transit network data, zonal data and synthetic population data (Atlanta Regional Commission, 2009). During trip generation, a mode choice log sum is calculated for each mode (including walking) in order to generate zonal accessibilities that are used in the multinomial logit destination choice model for every worker in the synthetic population (Atlanta Regional Commission, 2009). This mode choice log sum is calculated based on distance to the workplace and assumes peak period travel between zones. The mode choice model is based on the round-trip Level of Service by mode available. Mode choice model LOS parameters relevant to walk trips include walk access time, walk time up to 1 minute, walk time over one mile (Atlanta Regional Commission, 2009).

Currently, pedestrian trips are generated but are not assigned to the transportation network, due to the lack of pedestrian network link data and "ground truth" validation of pedestrian activity (K. Kim, June 19, 2013, personal communication). However, modeled pedestrian trips could be used in the future to estimate future non-motorized travel demand on a regional scale. Additionally, the use of pedestrian trip modeling data could provide information for all trip purposes (as the Census mode share data only includes aggregate data on the journey to work).

In the Atlanta region, several jurisdictions have established "Complete Streets" policies, which affirm the need to design for and accommodate all modes of transportation within plans and projects (Atlanta Regional Commission, 2013b). In 2012, the Georgia Department of Transportation (GDOT) adopted a "Complete Streets Policy" that is incorporated into the agency-wide Design Policy Manual. This policy includes criteria for consideration of bicycle, pedestrian and transit accommodations. The criteria for pedestrian accommodation states that pedestrian facilities "shall be considered" near to pedestrian travel generators, given the presence of "desire lines," if three-year crash records exceed ten pedestrian crashes per half-mile roadway segment, or when a planning study identifies a need (Georgia Department of Transportation, 2013).

A review of research and best practices related to evaluating walkability and prioritizing pedestrian infrastructure investments indicates a relationship between variables such as existing infrastructure condition, pedestrian activity and travel demand, land use and roadway characteristics. Generally, many prioritization "sketch planning" methods utilize a conceptual framework that combines a “pedestrian potential” (or demand-side) index with a “pedestrian deficiency (or supply-side) index to prioritize projects that may increase pedestrian activity while addressing current barriers to walkability and accessibility.

Based on the results of many walkability assessment studies and projects, the lack of pedestrian-scale data sources has been a barrier to refined analyses on local, regional and statewide scales. Particularly, sidewalk condition data and pedestrian activity data often limit the ability of researchers and practitioners to identify specific infrastructure needs and plan for future non-motorized travel demand. However, recent technological advances such as GPS-enabled mobile applications have the potential to address these data gaps and improve the cost-effectiveness of collecting disaggregate non-motorized transportation data.

Within the Atlanta region, programs and policies are emerging to promote active transportation and promulgate “Complete Streets” projects. Local, regional and statewide plans and policies indicate desired criteria for prioritizing pedestrian projects, which largely conform to foregoing best practices. Currently, sidewalk repairs are completed on an ad-hoc basis and local planners do not routinely inventory the condition of pedestrian infrastructure. Therefore, the development and application of a cost-effective sidewalk evaluation system has the potential to aid ongoing pedestrian planning and asset management.

CHAPTER 3

METHODOLOGY

3.1 Data Sources and Prioritization Criteria

The objective of this research is to demonstrate a process to prioritize areas for sidewalk repair or replacement within the City of Atlanta utilizing variables relevant to walkability and accessibility and incorporating app-collected sidewalk data. Based on a review of prior research and best practices, many pedestrian prioritization frameworks apply the conceptual framework of a “pedestrian potential index” representing variables related to travel demand and a “pedestrian deficiency index” incorporating infrastructure and safety indicators. Each index included several pedestrian project suitability indicators, which are then utilized to generate weighted spatial pedestrian prioritization rankings.

Census blocks are employed as the spatial unit of analysis for the prioritization rankings incorporating sidewalk data. Census blocks are the smallest geographic scale possible utilizing Census data, which was necessary to include demographic variables from the U.S. Census and the American Community Survey. Within the City of Atlanta, the geographic scope of analysis was limited to areas with available pedestrian activity data (the Midtown neighborhood) and further limited to Census blocks with processed sidewalk data available. Of the Census blocks with processed sidewalk width data, blocks were removed from analysis due to the lack of sidewalk width data available at the time of writing. Therefore, the final geographic scope was limited to 42 Census blocks within the Midtown neighborhood. This study area is in the vicinity of several public parks, a high school, the BeltLine Eastside Trail, the Technology Square mixed-use development, and three MARTA rail stations (see Figure 5).

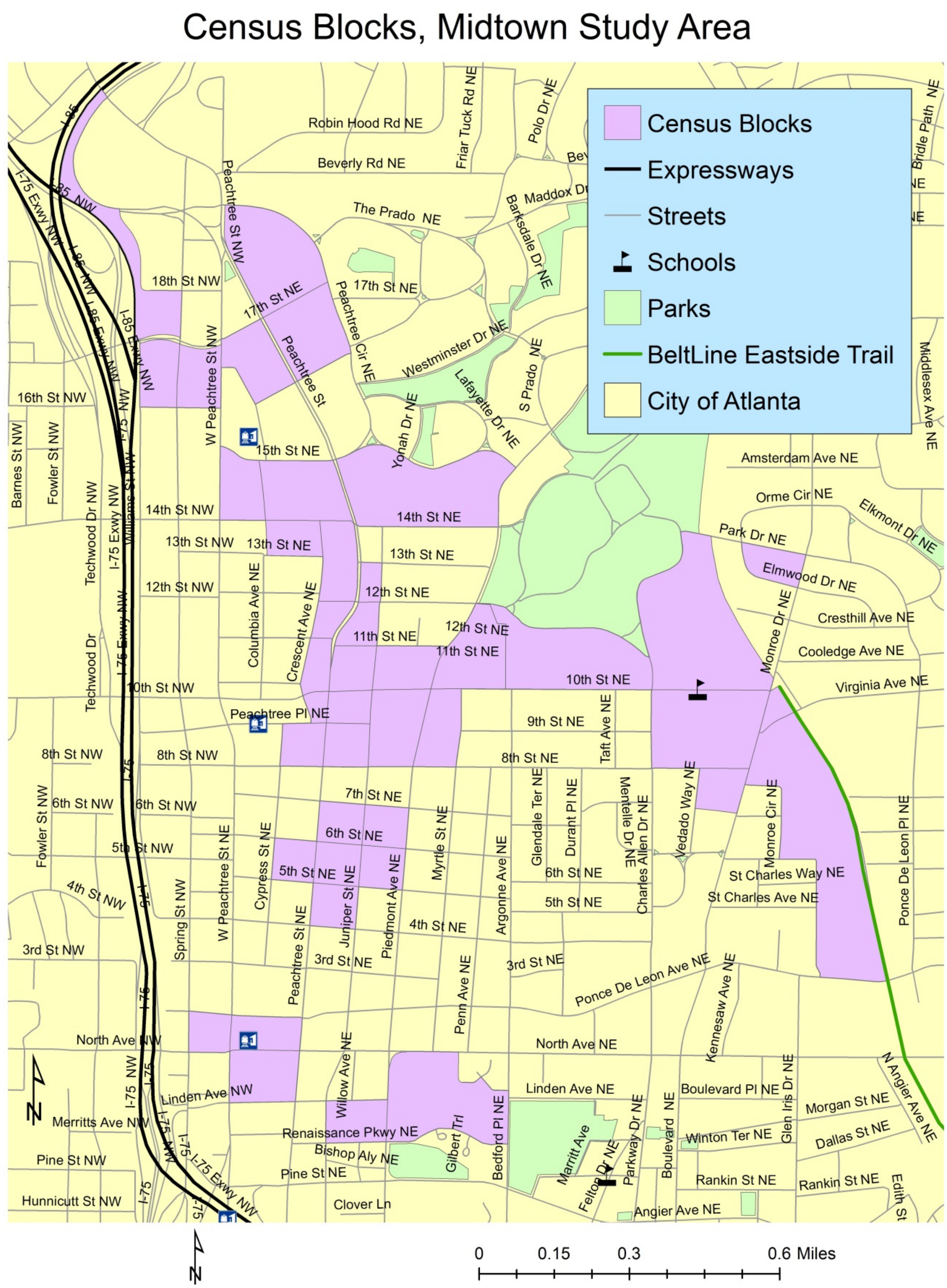

Figure 5: Pedestrian Prioritization Study Area, Midtown, Atlanta, GA

3.2 Data Sources and Data Reduction

The following datasets were used in pedestrian prioritization analyses: pedestrian count data, population density, transportation commute mode share, marketing demographic data, pedestrian crash data, and sidewalk width data. To prepare the pedestrian prioritization indices, the necessary datasets were obtained, linked to spatial information and aggregated to the Census block scale using ArcMap, IBM SPSS, Microsoft Access and Excel. The result of these data preparation and reduction tasks was a database table with the set of prioritization indicators by Census block. Thus, the set of Census blocks in the study area could be ranked and prioritized using each numeric indicator, and indicator-specific rankings could be combined to generate index ratings with different weightings.

3.2.1 Pedestrian Activity Data

Pedestrian count data were obtained from Midtown Alliance, a non-profit organization that represents members of the Midtown Community Improvement District. This dataset included pedestrian, motor vehicle, bicycle and bus/truck counts for weekday peak periods and a nine-hour weekend period, and the dataset included X-Y coordinates of each count location. Weekday counts were collected on Tuesday, March 26, 2013 with peak totals collected in the morning, midday and evening (Midtown Alliance, 2013a). Weekday counts were collected at 100 intersections in the vicinity of Midtown, and the dataset included morning, midday and evening count totals as well as overall weekday totals. Weekend counts were collected on Saturday, June 1, 2013 between 10am and 7pm at 17 intersection locations in Midtown.

The weekday pedestrian count data was utilized within the pedestrian prioritization analysis due to the greater geographic scope of the weekday pedestrian count data compared with the weekend count data. First, total weekday pedestrian counts were calculated for each intersection within the spreadsheet. Then, the X-Y coordinates of each pedestrian count intersection located were plotted using ArcMap. The pedestrian count point data were joined to the Census block using a spatial join of all pedestrian count data locations intersecting within 100 feet of Census block polygons. The point data that were located on the boundary of two Census blocks were joined to both blocks, and therefore the resulting dataset included 200 Census blocks. Finally, the maximum pedestrian count total (at a single intersection location) for each Census block was calculated using the summarize function in ArcMap. This resulting variable, "Max_Ped," was used as an indicator of block-level pedestrian activity for the rank-order prioritization analysis. Figure 6 shows the pedestrian count intersection locations within the study area. The map indicates that a majority of pedestrian count intersection locations from the Midtown Alliance dataset were located in the vicinity of the "Midtown Mile" along Peachtree Street.

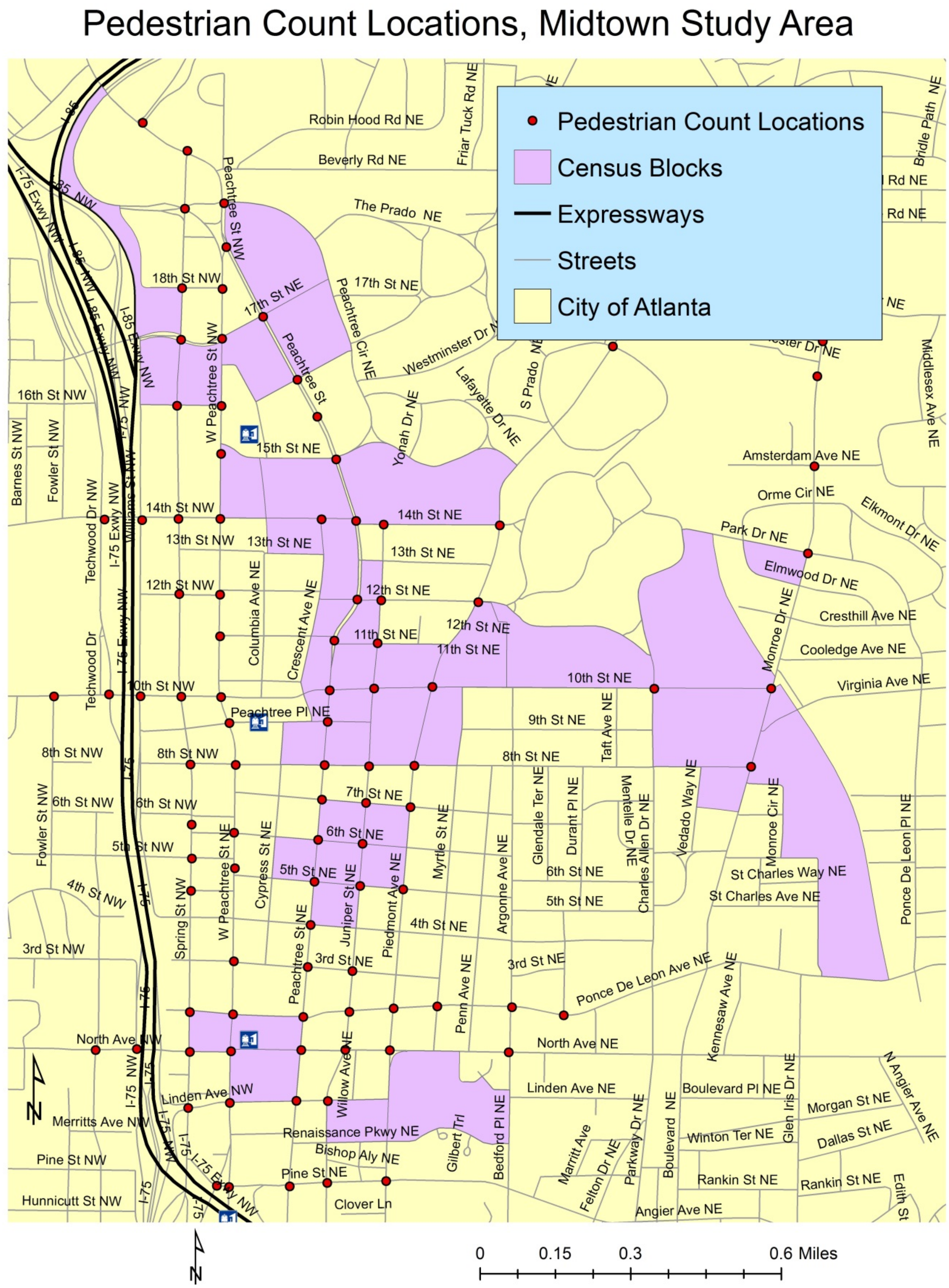

Figure 6: Pedestrian Count Intersection Locations

3.2.2 Population Density and Transportation Mode Share

The percentage of residents that commuted by walking, bicycling or riding transit was calculated as a measure of the number of residents in each tract that commute using "alternative" modes. The variable "means of transportation to work" by transportation mode was available from the 2010 American Community Survey at the Census tract scale.

Given that this variable was not collected at the Census block scale, the tract-level transportation mode share data were joined to each Census block located within it the Census ID codes of each tract and block. Although the values for Census tract mode share do not correspond exactly to the specific residents within each Census block, detailed mode share information was not available at the block scale and it is useful to include a commute mode indicator within a prioritization index. Population density was calculated as the total block-level population per block acreage using ArcMap with data from the 2010 Census.

3.2.3 Commercial Demographic Data

Georgia Tech purchased demographic data from a private data source to identify households within Fulton, DeKalb and Cobb counties with children ages 0-2 years and/or with residents with physical disabilities (mobility aid or wheelchair). The household-level marketing dataset were geocoded and aggregated to the Census block level using ArcMap. The percentage of households per Census block with mobility impairments or with young children within the Midtown study area was calculated using the number of housing units per Census block. The purpose of this indicator is to identify areas with greater accessibility needs to prioritize pedestrian improvements. Recent research incorporating private market data for socioeconomic analysis notes potential accuracy and data quality limitations in the application of marketing data (Khoeini & Guensler, forthcoming).

3.2.4 Pedestrian Crash Data

Pedestrian crash records for the years 2002-2009 were obtained from the GDOT incident database. The years of analysis were selected based on the most recent years of data that contained both a pedestrian incident table and a location table. For each year, the pedestrian incident table was joined to the location table in Microsoft Access to generate a table of pedestrian crashes with location information. Although 80% of crash records included X-Y coordinate information, 95% of incident records included RCLINK data. Therefore, the RCLINK field was used to calculate the number of crashes per Census block, which was added as a variable to the database table for each unique RCLINK identifier.

First, the statewide roadway shapefile was clipped to the Midtown study area within the City of Atlanta. The pedestrian incident table was joined to the roadway shapefile using the RCLINK identifier code. The sum of pedestrian incidents per RCLINK was calculated using the summarize function in ArcMap to identify the crash density per roadway segment. Next, the RCLINK-level crash database table was joined to the Census block shapefile so that the data for segments intersecting a single block were applied to the block polygon. Data for roadway segments located on the boundary of two Census blocks were applied to both Census blocks. The sum of pedestrian incidents per each RCLINK segment within a Census block was calculated using the aggregate function in IBM SPSS. Finally, the "Crash_sum" table was joined to the Census block shapefile in ArcMap and the crash sum variable was divided by block acreage to obtain block-level pedestrian crash density.

3.2.5 Sidewalk Width Data

As described in Chapter 2, the Sidewalk Sentry app developed at Georgia Tech collects video, gyroscope, accelerometer and GPS data, which are then used to assess sidewalk quality. Student employees and volunteers have collected field data within priority areas in the City of Atlanta, and this raw data is processed to obtain attributes such as pavement crack density, presence of obstructions and sidewalk width.

Many walkability indices and pedestrian level of service indices feature sidewalk presence or width as an important indicator for pedestrian infrastructure condition and physical accessibility. Therefore, sidewalk width is utilized in this research as an indicator for pedestrian infrastructure quality and accessibility. Additionally, ADA guidelines on accessible rights-of-way recommend that sidewalks have sufficient width to be traversable by individuals in a wheelchair (3-4 feet minimum), while the City of Atlanta Code of Ordinances states that sidewalks must be five feet in width (City of Atlanta Code §138.17). According to ADA guidelines, sidewalks less than 5 feet wide must contain adequate passing spaces for wheelchair users.

3.2.5.1 Sidewalk Width Video Processing

To incorporate sidewalk width data into a pedestrian prioritization framework, the relevant study area was identified and video data was prepared for processing to obtain sidewalk width data. The initial study area was limited to 200 Census blocks in the vicinity of Midtown, which intersected the 100 pedestrian count locations within the pedestrian activity dataset. The researcher mapped raw GPS data from Sidewalk Sentry field deployments, and selected those GPS points that intersected Census blocks within the study area. This initial dataset included approximately 72,000 GPS data points. A smaller sample of this dataset was processed due to time limitations and the need to use sidewalk data available at the time of thesis preparation. The database table with GPS point data included the video filename and timestamp of each GPS point, which was used to link GPS data with the video files. Next, the GPS point database table was joined to the Census block polygon shapefile using ArcMap to link GPS point data to Census blocks within the study area. GPS point data was joined to the Census block polygon it fell inside, and GPS points that were located in more than one polygon were joined to the first polygon (according to the default ArcMap procedure for a spatial join between point and polygon layers). This methodology may be refined in the future by joining GPS points located on the boundary of two block polygons to both polygons.

The timestamp for each GPS point was recorded in UNIX time, which measures the seconds that have passed since January 1, 1970. The start time of each data file was encoded into the automatically generated filename in "real time" along with a unique ID code for each Toshiba Thrive tablet. To prepare the video files for width estimation processing, it was necessary to identify the timestamp of each GPS point in relation to the start time of the video file. First, the video start time and the GPS UNIX timestamp were converted to the Microsoft Excel date and time format. Next, the video timestamp of each GPS point (in hours, minutes and seconds) was generated by subtracting the GPS timestamp from the video file timestamp. Thus, a spreadsheet was produced that linked second-by-second GPS data to its corresponding video filename, timestamp and Census block ID, which prepared the data for sidewalk width processing.

The prepared sidewalk width spreadsheet was used to identify the specific seconds within each video file that needed to be processed. Evangelos Palinginis conducted the video processing task using an edge detection algorithm in C# developed by Georgia Tech (Palinginis & Guensler, forthcoming) in order to estimate sidewalk width for each of the second-by-second GPS data points given the prepared spreadsheet.

100 GPS points within the study area were selected to test that the prepared spreadsheet corresponded accurately to spatial and video data. An undergraduate research assistant completed this quality control testing. The GPS coordinates were compared to their spatial location using Google Maps, and the video file was reviewed and compared with Google Street View in order to verify that the GPS data corresponded to the correct location. 98% of these 100 GPS points matched the geospatial location identified within the GPS data and video data. One GPS point, located at 14th Street and Peachtree Street, was several hundred feet from its location according to the video data and Google Street View. This discrepancy was assumed to be due to GPS locational accuracy issues caused by the presence of tall buildings. Two GPS points within the sample had a video filename that did not match the GPS coordinates or Google Street View. It was identified that approximately 340 GPS points had this filename, which corresponded to a neighborhood in southwest Atlanta. These GPS coordinates matched records already processed by the width estimation algorithm; however the algorithm did not recognize the incorrect filename. Therefore, it was assumed that the incorrect filename was assigned to these records after video processing due to an Excel recall error.

Figure 7 shows the GPS point locations within the study area with processed sidewalk width data, after GPS data cleaning. As shown by the map, there appear to be GPS accuracy issues at 14th Street, 10th Street and at North Avenue (at Peachtree Street), adjacent to high-rise office, hotel and residential buildings. The Census blocks adjacent to Piedmont Park have GPS sidewalk data only along 10th Street because that is the only public street within the block (the other streets shown are multi-use paths within Piedmont Park and on the BeltLine Eastside Trail).

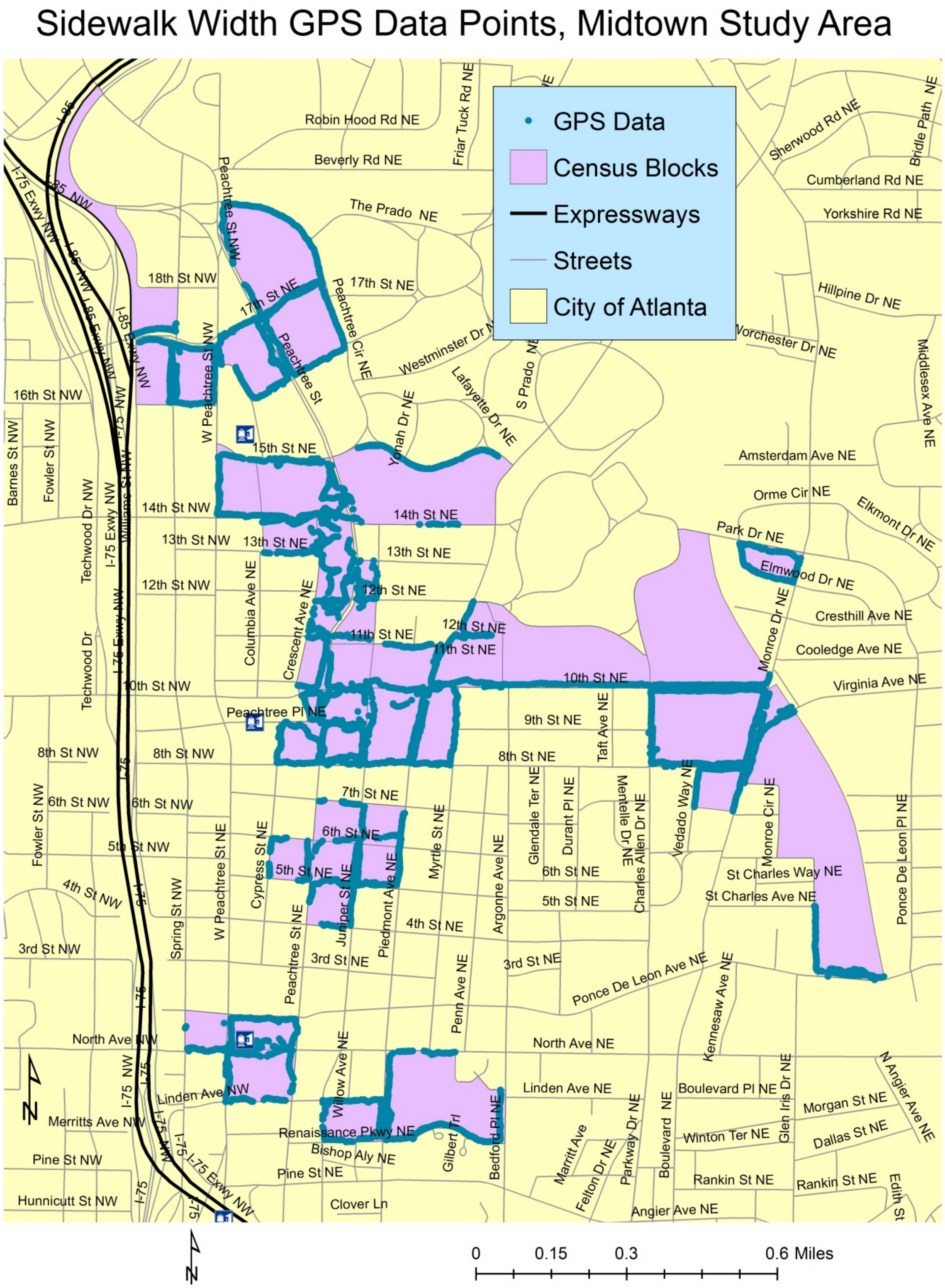

Figure 7: GPS Points, Field-Collected Sidewalk Width Data

3.2.5.2 Data Cleaning and Final Scope Selection

Video processing generated a database table with each record representing a GPS data point linked to estimated sidewalk width data. Next, the processed GPS data needed to be cleaned to remove duplicate records or inaccurate data points. First, records were removed with zero width (representing points with no sidewalk or points with no data), as well as values that were noted as "previously processed," "corrupted video" and "point does not exist in video." Next, records with duplicate timestamps and records with duplicate X-Y coordinate pairs were removed. Records with duplicate timestamps existed due to duplicated GPS records in multiple iterations of video processing.

Next, GPS data was displayed in ArcMap and five Census blocks were identified that had multiple data collection runs on a single block face. During field data collection, multiple runs were conducted to test various aspects of the application, as well as to gather data for a "before" and "after" study. However, the existence of multiple runs would bias block-level results towards that particular sidewalk segment. These repeated runs were removed in ArcMap by manually selected groups of data points corresponding to a single video file so that only one complete run remained for each block face.

GPS speed is recorded within Sidewalk Sentry™ and a speed of zero would denote points at which the data collection unit is stationary. When a GPS unit records a speed of zero, this implies GPS data position errors due to the Doppler Effect. Therefore, data points with a GPS speed of zero were removed. GPS data accuracy GPS data accuracy issues can also occur near tall buildings due to the frequent loss of lock and multipath errors due to sight obstructions and reflections of the GPS signal off of building surfaces (Wolf et al., 1999, Scheussler & Axhausen, 2009). It was assumed that GPS positional accuracy errors due to sight obstructions would not adversely impact the sidewalk width data, particularly given the scale of analysis (Census block). Further, that if individual GPS points were assigned to a block incorrectly due to GPS accuracy, it would not impact the block-level indicator results for the dataset as a whole.

Due to GPS accuracy issues due to sight obstructions and low GPS speed as well as "gaps" in GPS data points due to no sidewalk or lack of data, it was noted that the density of GPS points varied considerably within a single block. One might expect to observe a single GPS point every second (or 4.6 feet), however this was not consistently the case within the study area. Therefore, it was necessary to correct for GPS point density before calculating the percentage of sidewalk width data within each block with a certain width rating. The goal of this GPS point density correction is to down weight areas with high point densities and up weight areas with low point densities in order to achieve equal distance weighting throughout the study area. To reduce the potential bias caused by variations in GPS point density, each GPS record was weighted by a point density variable.

A grid cell was created in ArcMap and used to calculate the density of GPS points within a small area. Given that the average walking speed if 4.6 feet/second (approximately 3 miles/hour), 20 feet by 20 feet was established as a "conservative" cell size. A cell size was created that was several times the expected distance between GPS points to identify the GPS points with lower or higher densities than expected with second-by-second GPS data. Next, the researcher calculated the number of GPS points within each cell and aggregated the cell count per grid cell to each corresponding GPS point. A five feet search distance was used for this aggregation due to the fact that a small number of GPS points were located on the boundary between two or more grid cells. The average GPS density for each Census block was calculated using the Aggregate function in IBM SPSS, which identified the average GPS point density per cell for all GPS points within a single Census block. Then, the average GPS density per Census block was divided by the GPS density per point to achieve a GPS density weighting variable. The GPS point density weighting was used in order to increase the weighting of GPS points with low densities and decrease the weight of GPS points with high densities. The researcher utilized the Weight Cases function in SPSS to weight all GPS records by this GPS point density variable. Descriptive statistics were calculated for the weighted width data using IBM SPSS.

Based on the "N_Break" variable calculated during point density aggregation, six Census blocks were removed from analysis due to the small number of sidewalk width observations (less than 50). Several of these Census blocks consisted of one a single roadway segment, or included data points corresponding to neighboring Census blocks. As a result, the final geographic scope for prioritization analysis consisted of 42 Census blocks in the Midtown neighborhood within the City of Atlanta.

3.2.6 Sidewalk Width Data Categorization

The sidewalk width video processing conducted by Evangelos Palinginis generated a database table that included the estimated sidewalk width, X-Y coordinates and Census block ID for each GPS point within the study area. Using SPSS, numerical sidewalk width data was recoded into categories (see Table 4). As described below, width data were categorized to rate both points and calculate block-level indicators in relation to particular width thresholds based on accessibility guidelines and best practices.

Table 4: Categories for Sidewalk Width Ratings

Sidewalk Rating	Description
-1	No sidewalk
0	No data
1	0.001 < x < 3.000
2	3.000 <= x < 4.000
3	4.000 <= x < 5.000
4	5.000 <= x < 6.000
5	x >= 6.000

A rating of “1” represents an existing sidewalk that is not sufficiently wide for one wheelchair user to traverse safely. This category of sidewalk segment does not meet the minimum standard for accessible routes established by the ADA design guidelines (3 feet). A rating of “2” meets the ADA minimum standard for one wheelchair user to pass, however it would be necessary to provide additional width for wheelchair users to pass each other, for one wheelchair user to change direction, and to accommodate greater pedestrian traffic. The “3” sidewalk rating category meets the minimum standard of the proposed guidelines for accessible rights of way (PROWAG), as well as the minimum width stated by AASHTO pedestrian design guidelines (Proposed Accessibility Guidelines, 2011; AASHTO, 2004).

A rating of “4” meets the minimum sidewalk width established in the City of Atlanta code, provides sufficient width for wheelchair passing spaces or multiple pedestrians walking side-by-side. Additionally, this width adheres to the industry best practice recommended by the Institute of Transportation Engineers, the Federal Highway Administration and the Safe Routes to School program (ITE, 2010; FHWA, 1999; Pedestrian and Bicycle Information Center, 2013). Finally, a sidewalk rating of “5” exceeds the recommended practice for sufficient sidewalk width for all users to pass, and would accommodate greater pedestrian volumes.

Within the spreadsheet generated by video processing, data that corresponded to "no sidewalk" or "no data" were coded as zero (numerical width). Thus, it was not possible to differentiate between "no sidewalk " and "no data" records and therefore records with width ratings of 1-5 were selected for use in pedestrian prioritization ranking and spatial analysis. These data were recoded from numerical widths into sidewalk rating categories using IBM SPSS. Then, the percentage of GPS records within each category was aggregated by Census block. Finally, the researcher calculated the percentage of sidewalk width data within each block that corresponded to rating categories 1, 2 or 3.

This indicator represents the percentage of GPS data points for each block with sidewalk widths less than 5 feet. Although sidewalks less than 5 feet in width could accommodate one wheelchair user safely, it would be necessary to provide 5-ft wide passing spaces every 200 feet to be compliant with ADA accessibility guidelines (U.S. Access Board, 2002). Therefore, identifying the percentage of sidewalk data points with widths less than 5 feet may indicate either accessibility concerns or a need for further inspections to ensure full compliance. Therefore, this percentage was utilized as a block-level sidewalk width indicator for rank-order area prioritization analysis.

3.3 Weighted Rank-Order Prioritization

3.3.1 Rank-Order Analysis

Multicriteria ordinal rankings have been used to evaluate alternatives in many research areas, including the assessment of capital construction projects such as transportation investments (Cook & Kress, 1994). One application of this basic methodology is the analytical hierarchy process, in which alternatives are scored on a set of quantitative or qualitative indicators in order to inform decision-making. Multi-criteria index ranking analysis has also been used in prioritizing spatial areas within decision-making, such as in land suitability analysis (Hill et al., 2005). This research applies a multicriteria index decision-making methodology to assess the suitability of Census blocks for pedestrian investment, with the goal of improving current infrastructure deficiencies where there is potential for increases in pedestrian travel demand. This framework applies the general approach employed by the City of Portland and New Jersey DOT in formulating pedestrian deficiency and potential indices to prioritize pedestrian projects (Schwartz et al., 1999, Swords et al., 2004)

The general process for creating a rank-order prioritization index is to prepare a set of variables and generate rankings for each variable. In the case of the Midtown study area, the Census blocks were ranked from 1 to 42 (in the case of no repeated rankings) based on each individual variable. Next, the rankings for each variable in the index were totaled, and then these rank sums were rank-ordered. This second rank ordering result denotes the ranking of each Census block within the study area based on a combination of the individual rankings for each variable within an index. Table 5 shows an example of these individual variable rankings and composite rank scores for one index. Note that these rankings correspond to the entire dataset of 42 blocks and only a small sample is shown for illustrative purposes.

Table 5: Example of Rank-Order Prioritization Index

Census Block ID	Crash Variable	Width Variable	Crash Rank Score	Width Rank Score	Rank Sum	Composite Rank Score
131210002005005	25.55	2.65	4	7	11	3
131210004001002	0.24	0.78	10	10	20	13
131210004001003	0.05	2.71	12	6	18	10
131210004001006	108.39	0.11	1	14	15	5
131210004001015	0.00	2.99	13	5	18	10
131210004001016	94.54	0.17	2	13	15	5
131210004002008	3.84	0.00	6	15	21	14

3.3.2 PPI and PDI Rank-Order Prioritization and Spatial Analysis

The next analysis step was to combine the data sources into "potential" and "deficiency" indices by Census block. These indices assume equal variable weighting, but variable weightings can be easily assigned to any category. As shown in Table 6, the PPI index included pedestrian activity, population density, transportation mode and demographic variables. A GIS database table was exported that included the four PPI variables and two PDI variables by Census block.

Table 6: Prioritization Indices: Indicators and Data Sources

Index	Indicator	Variable	Data Source
Pedestrian Potential Index	Pedestrian activity	Maximum six-hour pedestrian count	Midtown Alliance
	Population density	Population per acre	2010 Census
	Transportation mode share	Percentage of transit, walk and bicycle commute mode	ACS
	Households, persons with disabilities	Percentage of households with disabilities/young children	Private data source
Pedestrian Deficiency Index	Sidewalk width	Percentage of GPS points, sidewalk width less than 5 feet	Georgia Tech
	Pedestrian crash density	Pedestrian crashes per acre	GDOT

The PDI (pedestrian deficiency index) is comprised of sidewalk quality and pedestrian safety variables. A GIS database table was exported that included the two PDI variables by Census block. First, Census blocks were ranked by sidewalk width using the highest percentage of data points with a width rating of 1-3 (sidewalk width between 0.001 and 4.999 feet). Census blocks were also ranked in descending order by pedestrian crash density. To prepare the pedestrian potential index, first each variable was rank-ordered. Assuming that each variable is weighted equally, summing the results of the rank-order for each variable generated the composite PPI ranking. The sum of each variable ranking was then rank-ordered to generate a combined ranking of Census blocks based on the PPI variables. Next, a combined Census block weighted ranking was generated for each variable (see Table 7). The researcher generated thematic maps for each PPI ranking by Census block within the study area.

Next, each variable within the pedestrian deficiency index was rank-ordered. Assuming that each variable is weighted equally, summing the results of the rank-order for each variable generated the composite PDI ranking. The sum of each variable ranking was then rank-ordered to generate a combined ranking of Census blocks based on the PDI variables. Next, a combined Census block weighted ranking was generated for each variable (assuming that the variable of interest would be weighted 60% and other variable is weighted 40%). The PPI and PDI weighted ranking formulas are shown in Table 7.

Table 7: Pedestrian Potential and Pedestrian Deficiency Index Weightings

	Index	
Weighting	Pedestrian Potential Index	Pedestrian Deficiency Index
Unweighted	*Activity + Mode + Disability + Density*	*Width + Crash*
Pedestrian Activity	*Activity*0.6 + Mode*0.1333 + Disability*0.1333 + Density*0.1333*	--
Mode Share	*Activity*0.1333 + Mode*0.6 + Disability*0.1333 + Density*0.1333*	--
Disability	*Activity*0.1333 + Mode*0.1333 + Disability*0.6 + Density*0.1333*	--
Population Density	*Activity*0.1333 + Mode*0.1333 + Disability*0.1333 + Density*0.6*	--
Sidewalk Width	--	*Width*0.6+ Crash*0.4*
Crash Density	--	*Width*0.4+ Crash*0.6*

3.3.3 Composite Suitability Index: Rank-Order Prioritization and Spatial Analysis

The researcher summed the results of the unweighted PDI and PPI rankings to generate a composite index ranking. Additionally, the researcher generated a composite ranking score weighted to the PDI index result and a composite ranking score weighted to the PPI index result (the formulas for these three composite indices are shown in Table 8). The aim of generating a composite index ranking score using both PPI and PDI results is to identify the Census blocks that should be prioritized based on their potential for pedestrian demand as well as current infrastructure and safety deficiencies. Thus, by summing the results of both the PPI and PDI rank scores, the composite score will rank most highly the blocks with both current pedestrian demand as well as need for facility improvements.

Table 8: Composite Index Weightings

	Index
Weighting	Composite Index Ranking
Unweighted	$PDI_{unweighted} + PPI_{unweighted}$
PPI	$PDI_{unweighted}*0.4 + PPI_{unweighted}*0.6$
PDI	$PDI_{unweighted}*0.6 + PPI_{unweighted}*0.4$

CHAPTER 4

RESULTS

4.1 Data Sources

The researcher presented the data for each pedestrian potential and deficiency indicator as a Census-block level thematic map by quantile. The intent of these variable-specific thematic maps is to enable the researcher to compare the effects of each indicator individually. Additionally, the researcher presented the sidewalk width data results as a thematic map for the percentage of GPS data points within each rating category (1-5) as well as from categories 1-3. Finally, the researcher presented the weighted and unweighted results for the pedestrian potential index, the pedestrian deficiency index and the composite index as a thematic map. For these index prioritization maps, the highest-rated Census blocks are represented as warmer colors and the lower-rated Census block are represented as cooler colors. The intent of presenting each variable and index weighting separately is to enable comparisons between the effects of different pedestrian prioritization indicators. As noted previously, the study area consisted of 42 Census blocks within the Midtown neighborhood in Atlanta, Georgia.

4.1.1 Pedestrian Activity Data

Figure 8 shows the maximum weekday pedestrian count location within each Census block within the study area. The map indicates that the highest weekday pedestrian count intersections were located within the vicinity of Colony Square and the Arts Center MARTA station, with a secondary pedestrian activity area near the North Avenue MARTA station (and to a lesser extent, near the Midtown MARTA station). In addition to the presence of rail transit stations, the highest pedestrian activity areas include office buildings and restaurants/shopping.

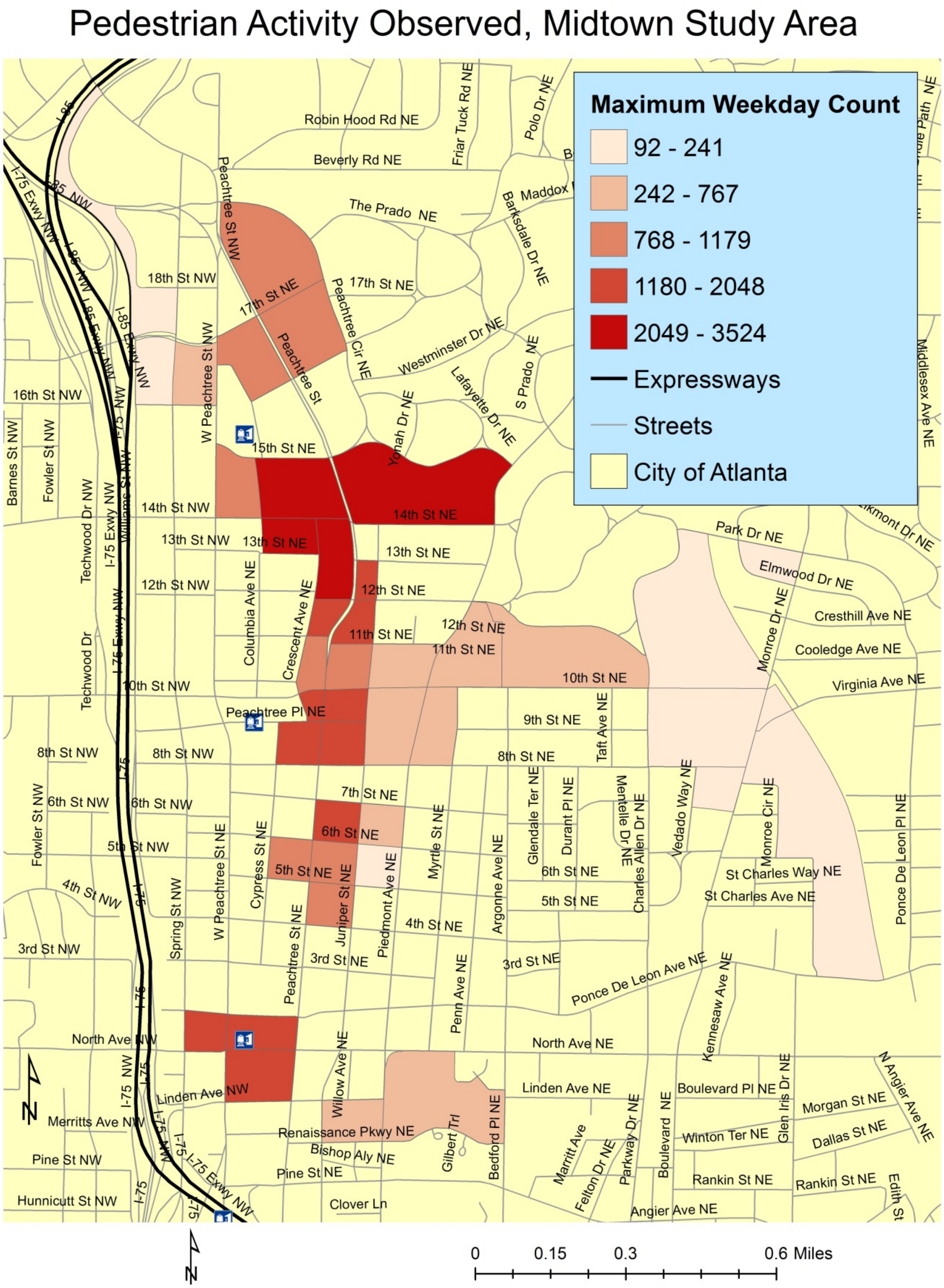

Figure 8: Pedestrian Activity by Census Block

4.1.2 Population Density and Transportation Mode Share

Figure 9 shows the percentage of non-auto commute mode share aggregated to the Census block within the study area. The map indicates that the Census blocks with the highest tract-level percentage of total transit, bicycle and pedestrian commute mode share are located near the Midtown and North Avenue stations. Further, several blocks within the Midtown residential neighborhood had a high percentage of non-auto commute mode share. Several of these blocks (between 4^{th} and 7^{th} Street, and surrounding the intersection of North Avenue and Peachtree Street) are located within walking distance of the Technology Square mixed-use development and the Georgia Tech campus

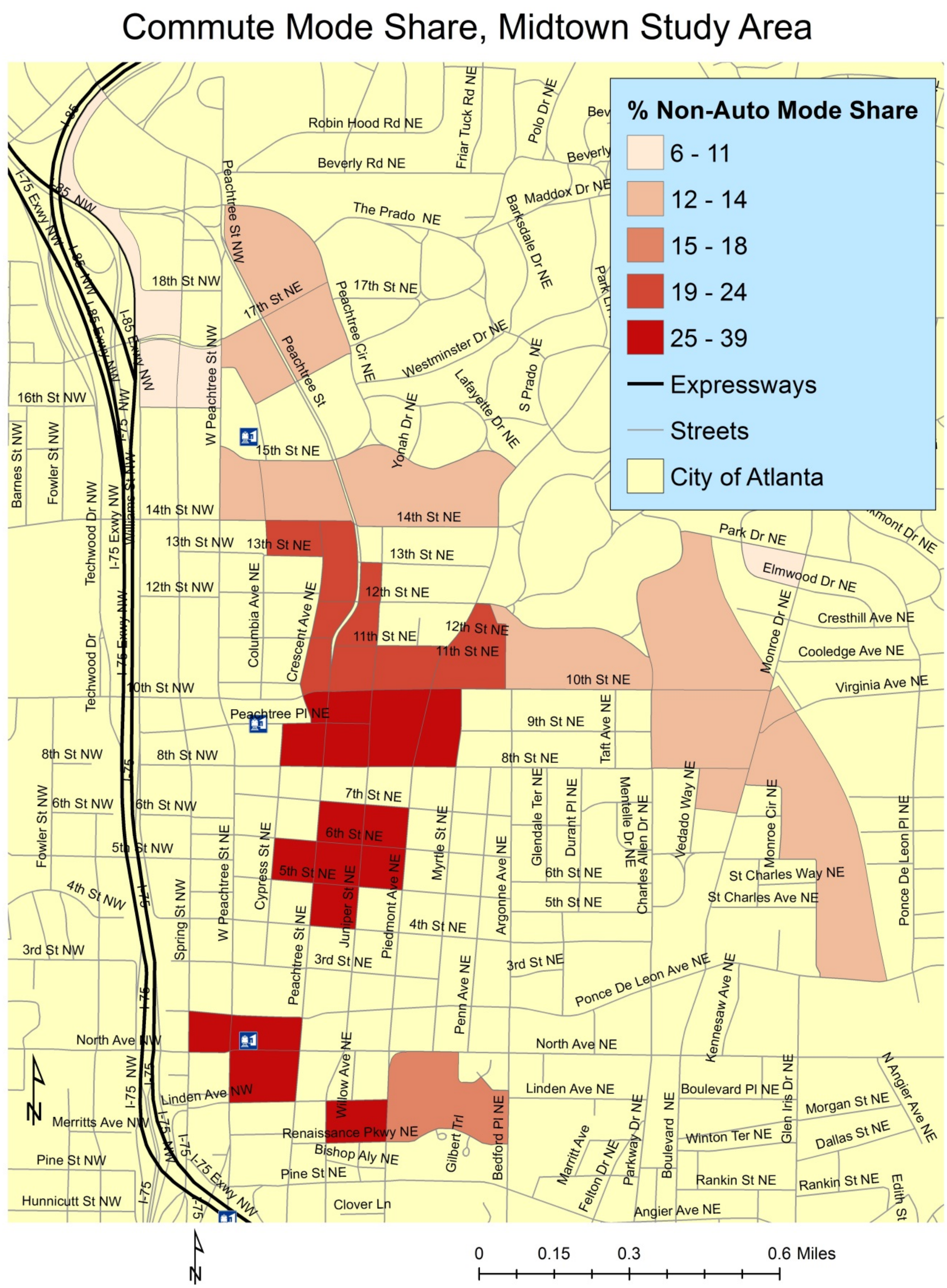

Figure 9: Tract-Level Commute Mode Share, Aggregated to Census Block

Figure 10 shows the population density (per block acreage) within the study area. The map indicates that the Census blocks with the highest population density are located near the North Avenue MARTA station and within the Midtown residential area. Additionally, blocks at Crescent Avenue and at 14th Street had high population densities, although the surrounding blocks had lower densities. These results indicate the presence of high-density residential buildings adjacent to other uses (i.e. commercial buildings) with low or no population.

Additionally, given that the commute mode share data was available only at the Census tract level, these results may indicate the effect of high-density blocks surrounded by low-density blocks within tract-level Census data. For example, although the blocks between Peachtree Place and 14th Street were rated within the second highest quartile for aggregate commute mode share, the population density data indicates that the block-level population density is very high within one block and very low in surrounding blocks. In future research, parcel-level land use data is needed to calculate micro-level population and building unit densities for use in pedestrian potential analyses.

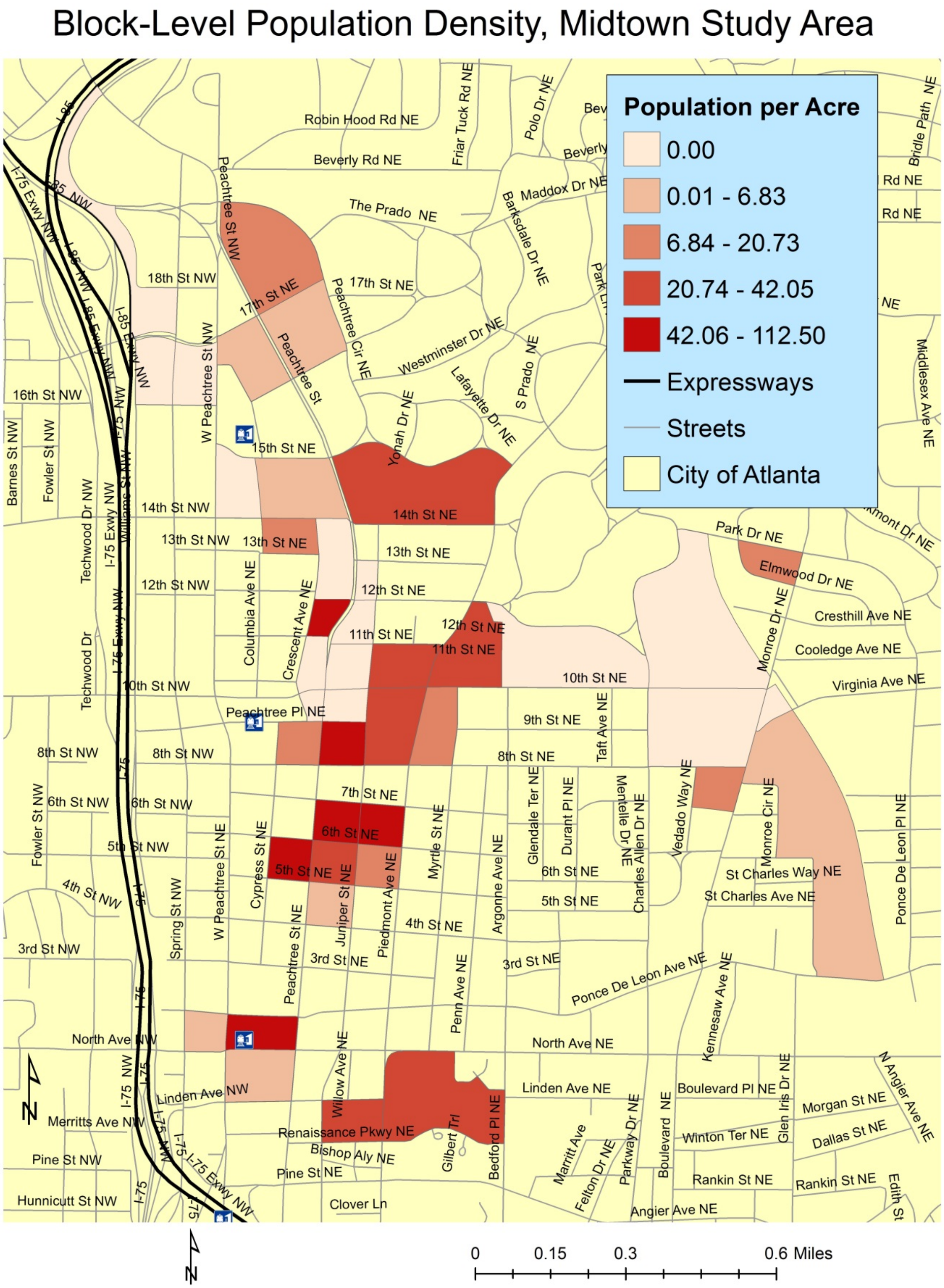

Figure 10: Population Density by Census Block

4.1.3 Commercial Demographic Data

Figure 11 shows the block-level percentage of households with accessibility needs within the study area. The map indicates that the Census blocks with the highest percentage of households with mobility impairments and young children are located near the Arts Center, Midtown and North Avenue MARTA stations. Additionally, the block near 10th Street and Monroe Drive was in the second-highest quartile based on commercial demographic data on mobility impairments. Although one block found that 100% of its housing units had households with disabilities (the percentage value of 1.0), this is likely due to the small number of residential units within this block.

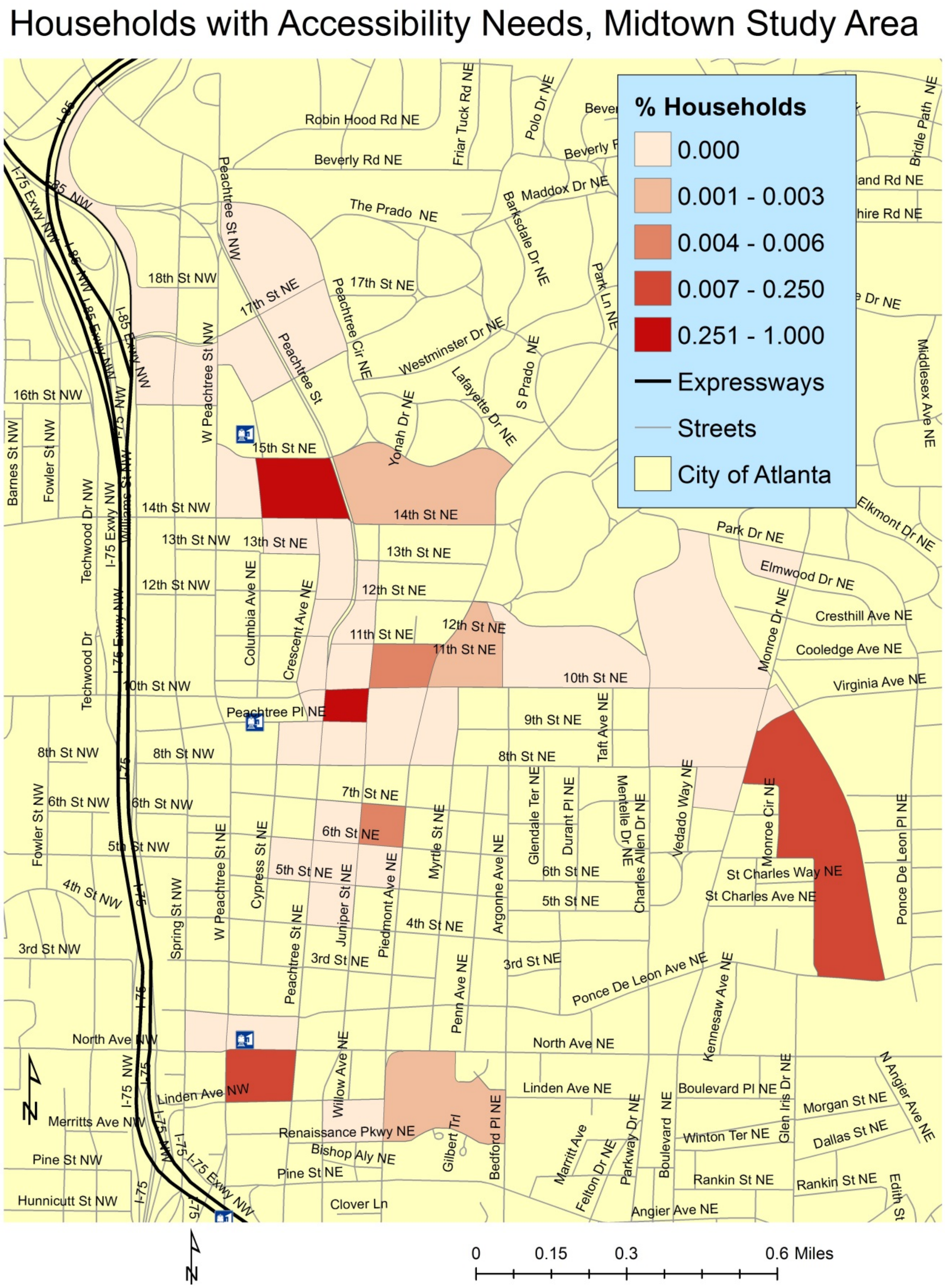

Figure 11: Percentage of Households with Access Considerations by Census Block

4.1.4 Pedestrian Crash Data

Figure 12 shows the block-level pedestrian crash density within the study area. The map indicates that the Census blocks with the highest pedestrian crash density are located along higher-volume roadways and near the three MARTA rail stations. For example, several blocks within the highest pedestrian crash density quartile are located near Peachtree Street and West Peachtree Street and in the vicinity of entrances onto the interstate system, which are likely to have heavy traffic volumes and high speeds.

Additionally, several blocks adjacent to Monroe Drive were in the highest and second-highest quartile for pedestrian crash density, which may indicate pedestrian safety concern along that corridor. It is worth noting that the pedestrian crash data included in this analysis were collected before the completion of the BeltLine Eastside Trail as well as the pedestrian safety improvements at 10th Street and Monroe Drive adjacent to Piedmont Park. Thus, prioritization is an evolving process that must be responsive to changes in infrastructure and travel demand.

Pedestrian Crash Density, Midtown Study Area

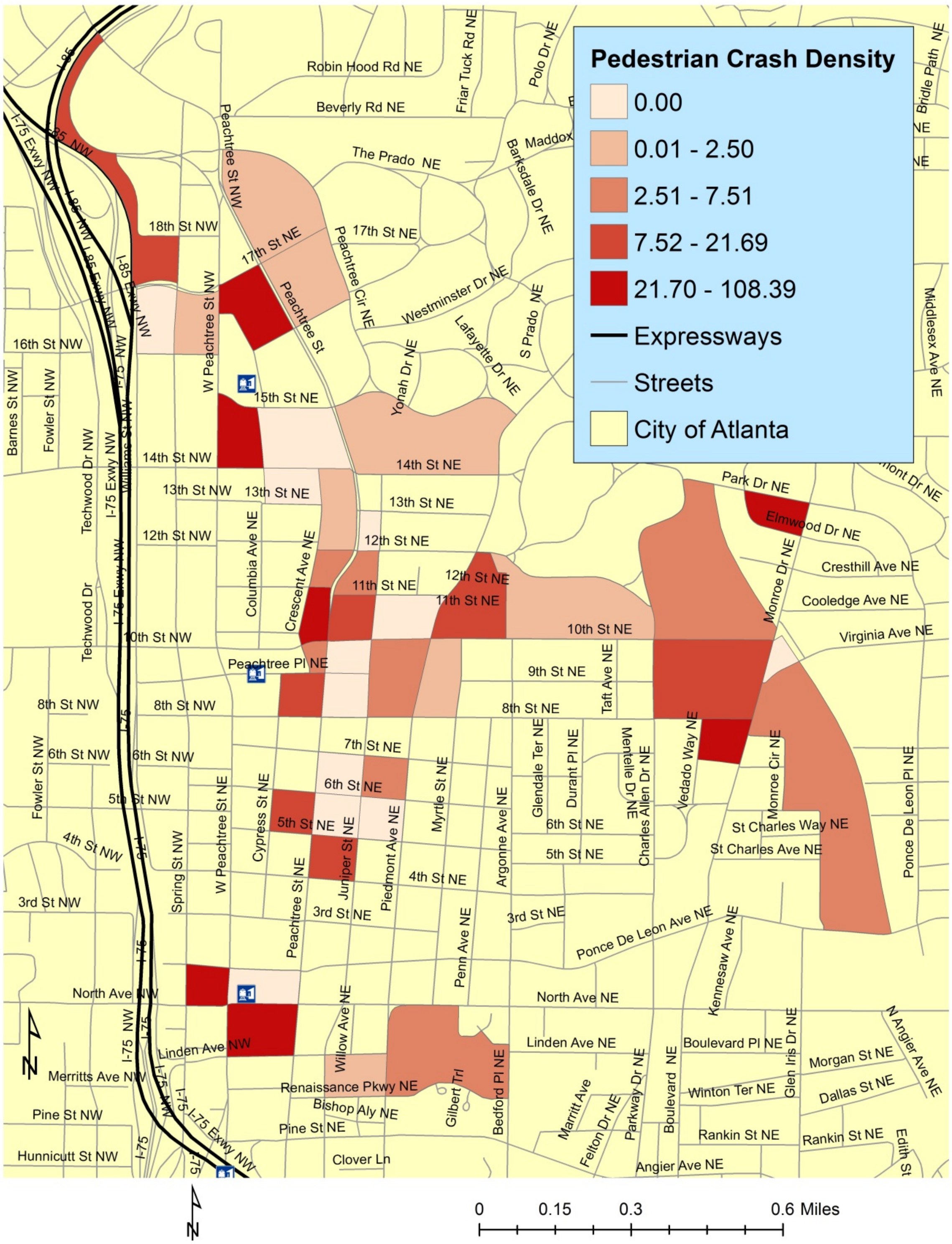

Figure 12: Pedestrian Crash Density by Census Block

4.2 Sidewalk Width Data

4.2.1 Width Data Descriptive Analysis

Descriptive statistics for the numerical and categorized sidewalk width data were calculated using IBM SPSS. Table 9 shows the calculated descriptive statistics for the numerical sidewalk width data weighted by GPS point density. The Weight Cases function in SPSS synthetically increased the number of cases in order to increase the weighting of GPS points with low densities. The mean estimated sidewalk width was 9.0 feet, and the median sidewalk width was 7.8 feet, while less than 25% of the sidewalk width data was less than 6.3 feet. These results indicate that sidewalk width data within the study area largely exceeded the minimum standards for accessible routes. However, the standard deviation (4.035), as well as the difference between the median and mean values, indicates a high degree of variability within the data.

Table 9: Descriptive Statistics, Numerical Sidewalk Width Data Weighted by GPS Density

N		18,893
Mean		8.992
Median		7.801
Mode		6
Std. Deviation		4.035
Minimum		0.013
Maximum		32.001
Percentile	25	6.3
	50	7.801
	75	10

Figure 13 shows the histogram for numerical sidewalk width data within the study area. The histogram indicates that the majority of the sidewalk data points had sidewalk widths between 5 feet and 10 feet. However, over 500 weighted records had a sidewalk width of 20 feet. This extreme width values are likely due to sidewalk width zoning requirements along Peachtree Street that call for sidewalk widths (not including street furniture space) of 15 feet. The histogram suggests that sidewalk width data within the study area has a long right-hand tail of variance.

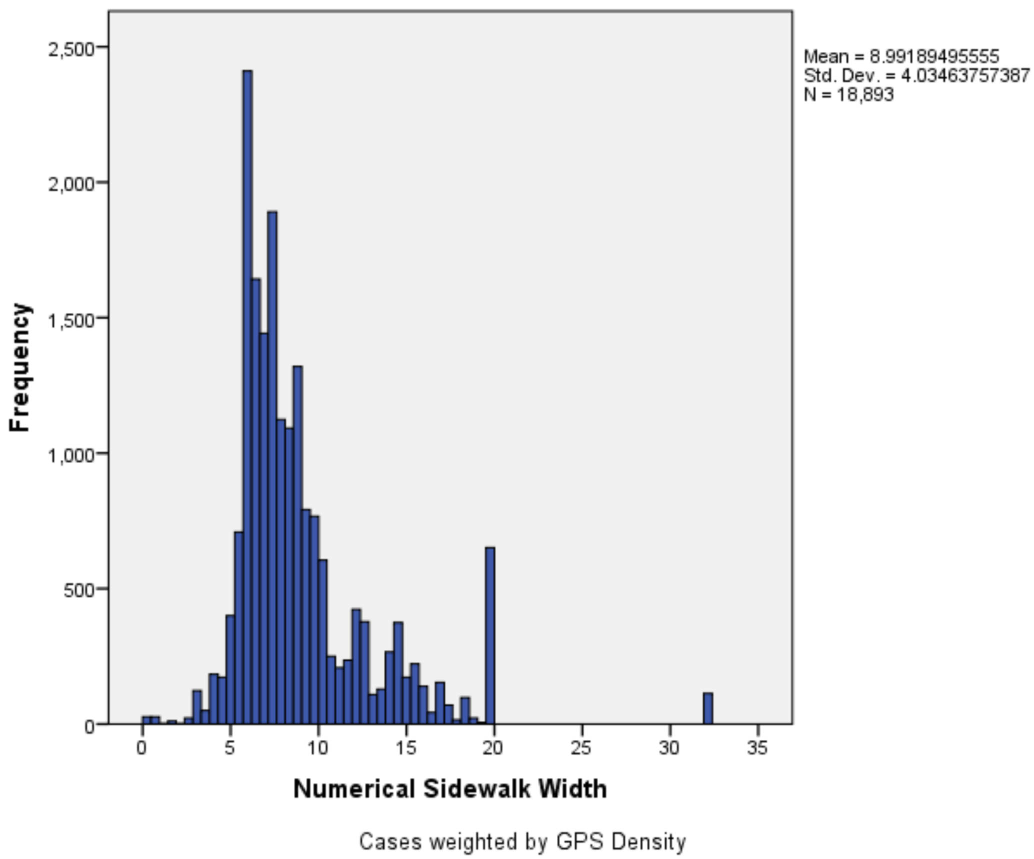

Figure 13: Histogram, Numerical Sidewalk Width Data

As described in Chapter 3, sidewalk width data were recoded into five categories representing thresholds for minimum and recommended sidewalk widths for accessibility and walkability. Figure 14 shows the histogram of sidewalk width data categories within the study area. The histogram indicates that the majority of sidewalk data were rated as width category 5, representing widths greater than six feet. Based on the frequency and descriptive statistics calculated by SPSS, 89.4% of data points in the study area were rated a “5” based on sidewalk width. 7.1% of the sidewalk width data corresponded to width category 4.

These sidewalk width results do not necessarily reflect sidewalk quality or infrastructure condition patterns in other neighborhoods within the City of Atlanta. For example, width hand measurements collected on a calibration route within the Virginia-Highland neighborhood had an average width of 5.11 feet and a median width of 4.95 feet, with only 4.4% of width measurements greater than 6 feet (width category 5).

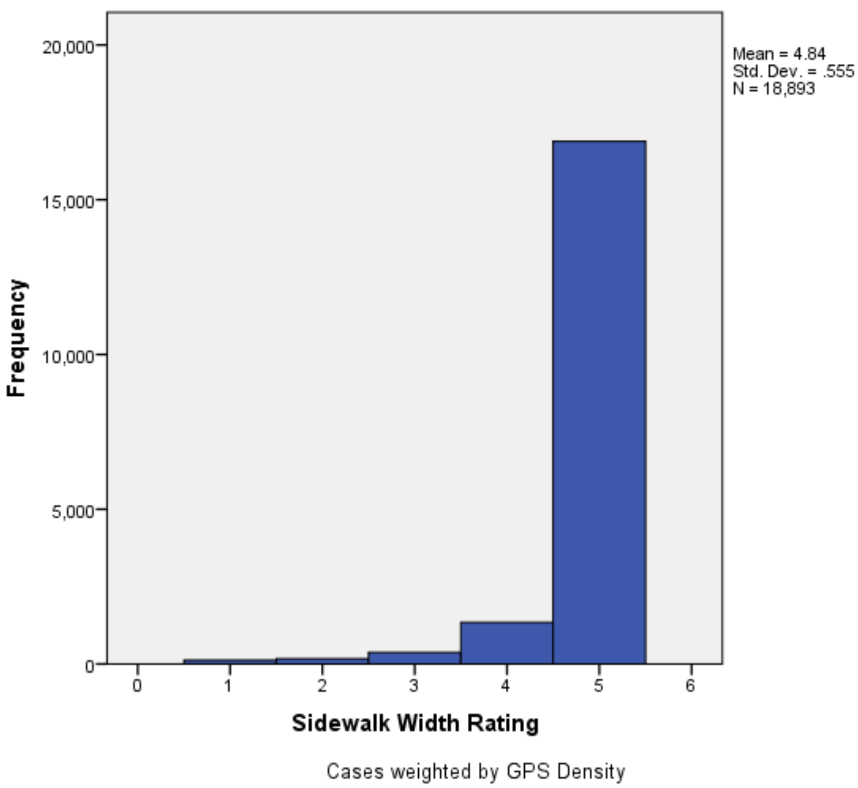

Figure 14: Histogram, Categorical Sidewalk Width Data

4.2.2 Sidewalk Width Data Spatial Analysis

Using ArcGIS, thematic maps were generated for the study area representing the percentage of sidewalk width data within each rating category. Figure 15 shows the percentage of sidewalk width data within each Census block with a width rating of 1. The highest quartile represents Census blocks with the highest percentage of sidewalk data that does not meet the minimum standard for accessibility under ADA guidelines. The results indicate that the blocks with the highest percentage of "1" sidewalk width ratings were located along 5^{th} Street between Peachtree Street and Piedmont Avenue, and within the block near Peachtree Street between 12^{th} Street and 15^{th} Street. The highest percentage of block-level sidewalk data with the lowest rating was 15.7%.

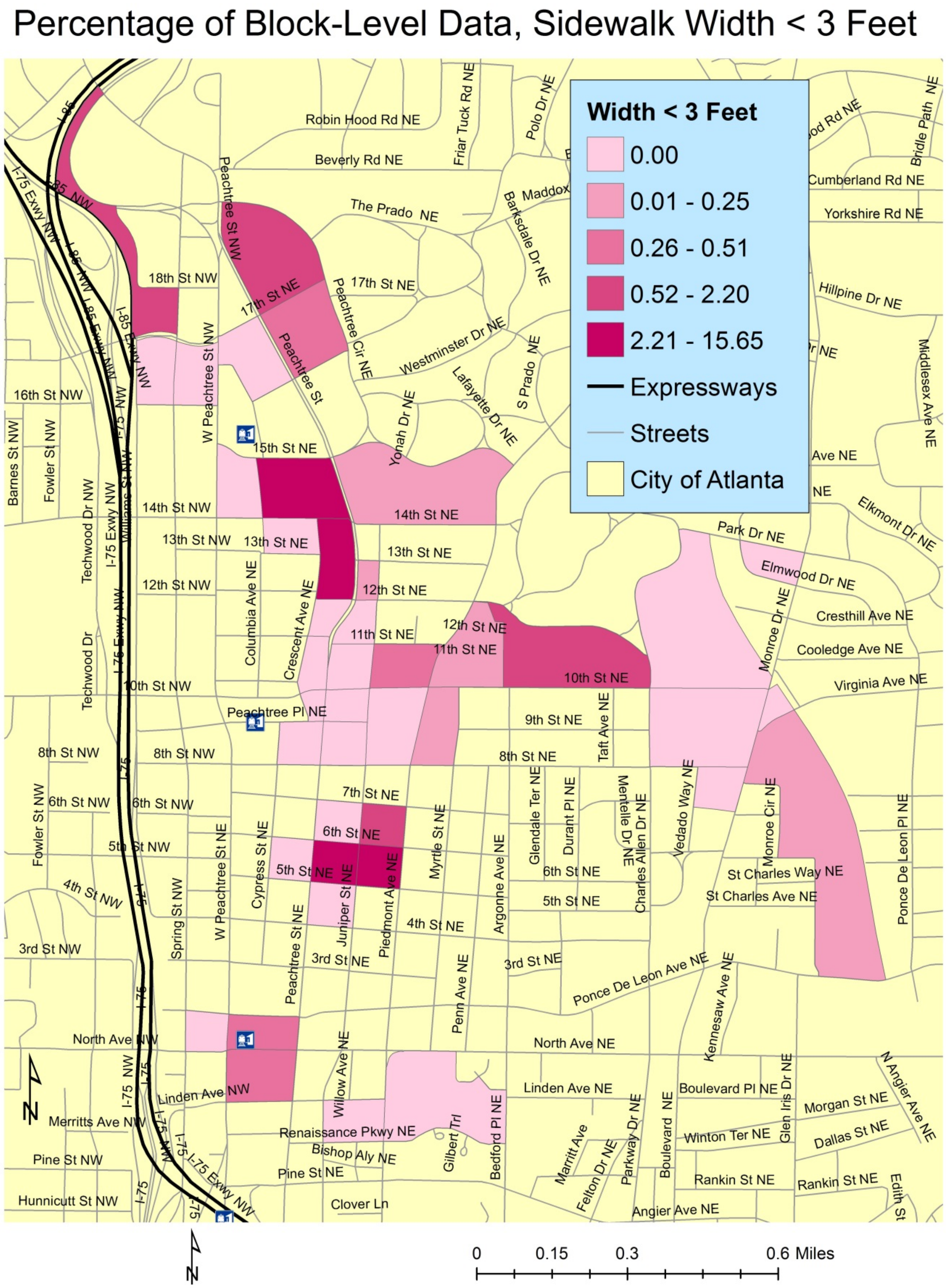

Figure 15: Percentage of Sidewalk Width Data, Rating 1

Figure 16 shows the percentage of sidewalk width data within each Census block with a width rating of 2. The highest quartile represents Census blocks with the highest percentage of sidewalk data that are between 3 feet and 4 feet. Few blocks had a sidewalk width rating of 2, as the highest percentage of block-level sidewalk data with the second-lowest rating was 5.07%. The results indicate that the blocks with the highest percentage of “1” sidewalk width ratings were located along Peachtree Street and along Monroe Drive.

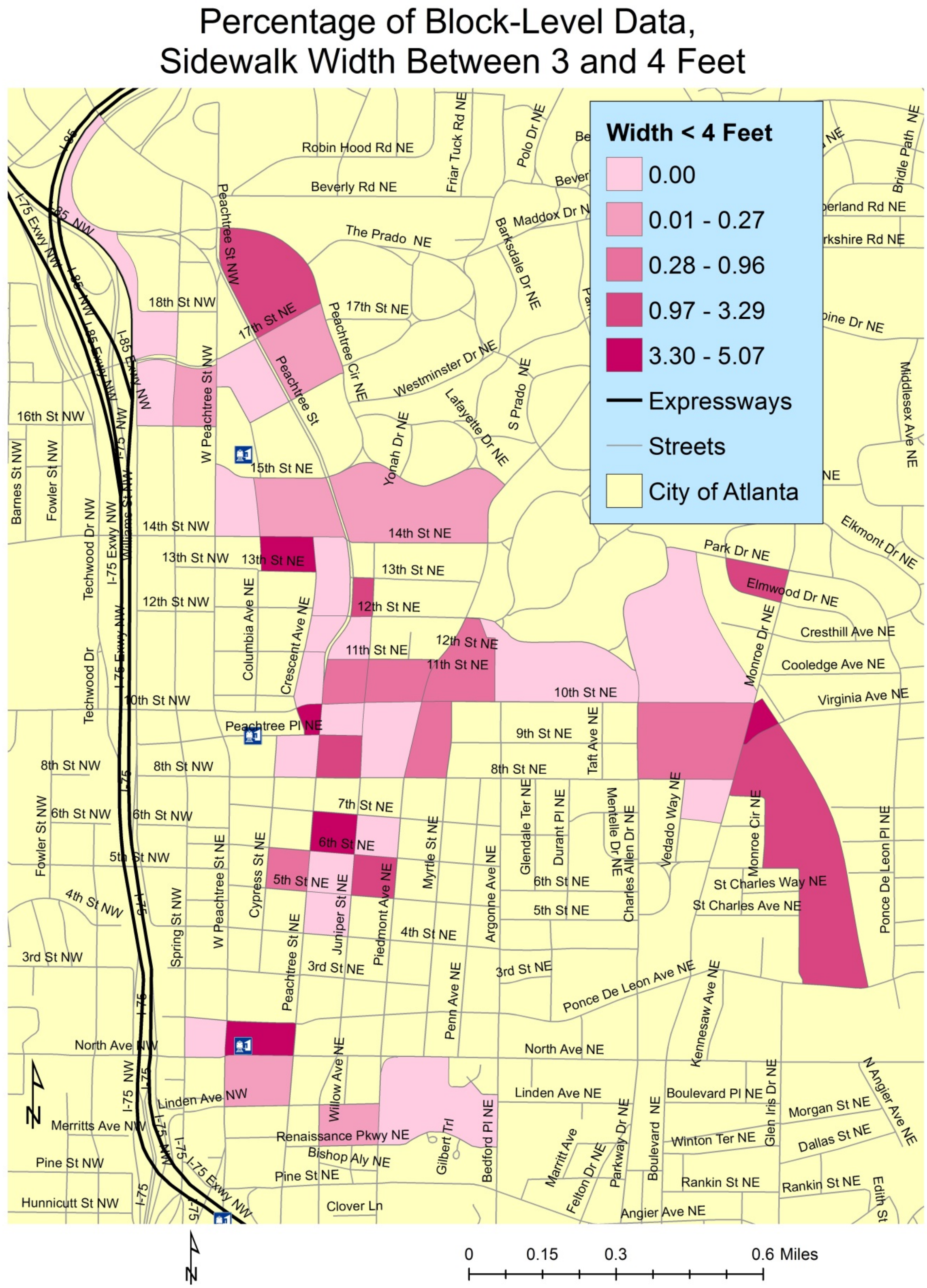

Figure 16: Percentage of Sidewalk Width Data, Rating 2

Figure 17 shows the percentage of sidewalk width data within each Census block with a width rating of 3. The highest quartile represents Census blocks with the highest percentage of sidewalk data that are between 4 feet and 5 feet. Widths within this category meet the minimum ADA and AASHTO standard; however width would not be sufficient for wheelchairs to pass each other safely. The results indicate that the blocks with the highest percentage of “3” sidewalk width ratings were located adjacent to the North Avenue MARTA station and along Monroe Drive near the intersection at 10th Street. Several blocks within the Midtown residential neighborhood (between 4th Street and 10th Street) had the highest percentage of width data in this category; however this rating percentage was not consistent within the immediate area.

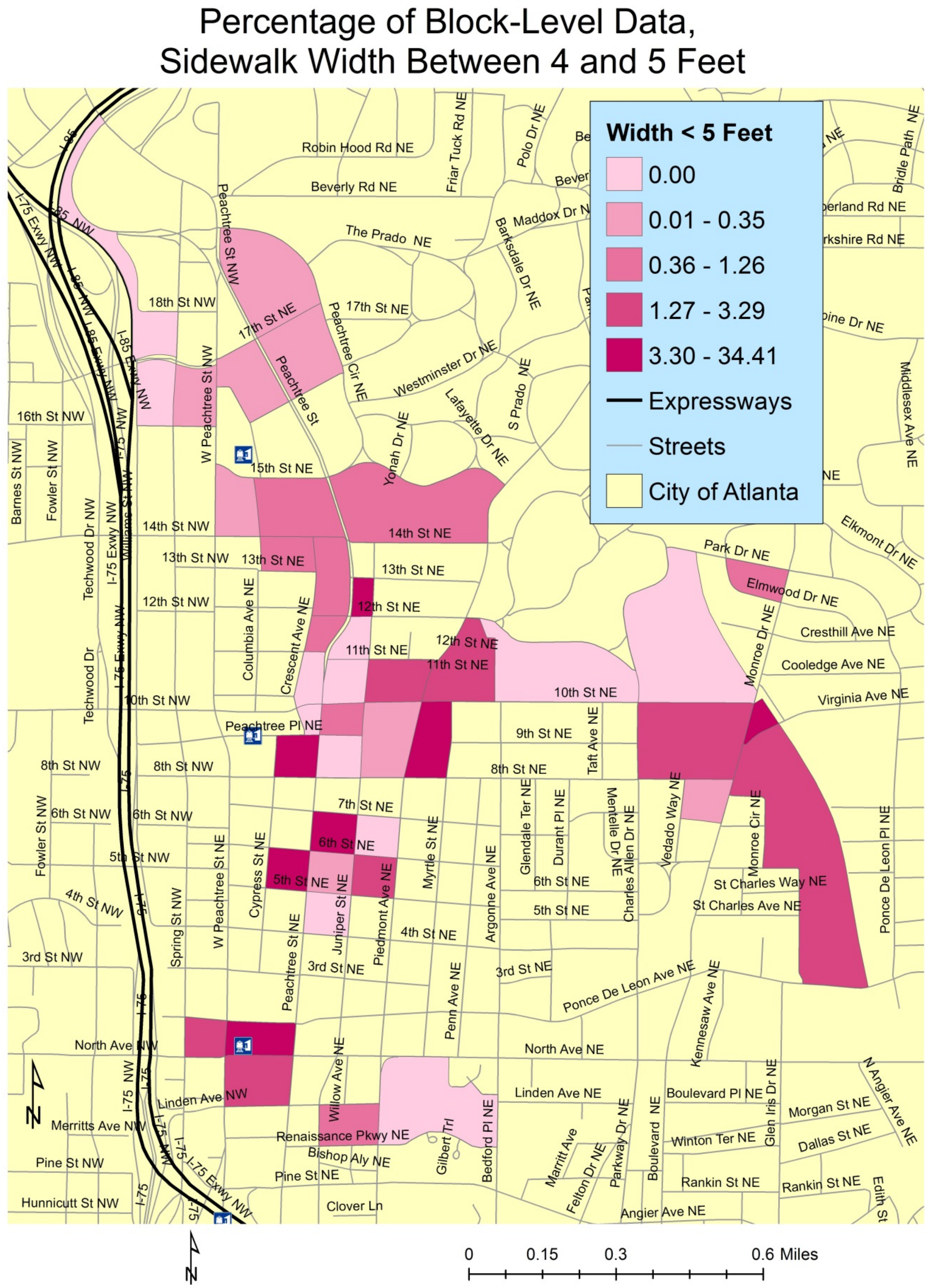

Figure 17: Percentage of Sidewalk Width Data, Rating 3

Figure 18 shows the percentage of sidewalk width data within each Census block with a width rating of 4. The highest quartile represents Census blocks with the highest percentage of sidewalk data that are between 5 feet and 6 feet. Sidewalk width data rated within this category would provide sufficient space for wheelchair users to traverse and pass safely. The results indicate that the blocks with the highest percentage of “4” sidewalk width ratings were located in small groups within the Midtown residential neighborhood (i.e. between 5th Street and 7th Street and at 14th Street and Peachtree Street) and in select blocks near the intersection of Monroe Drive and 10th Street.

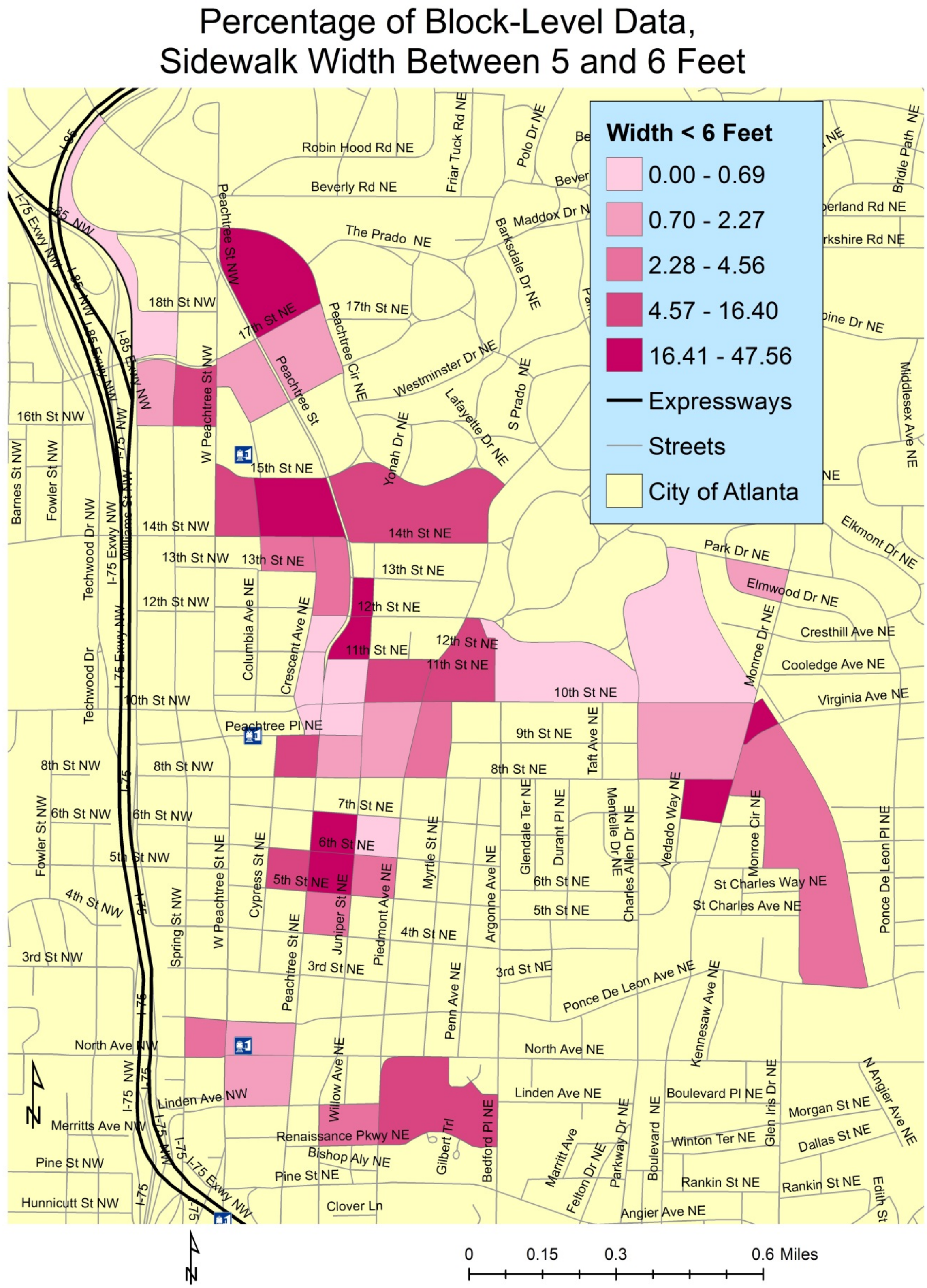

Figure 18: Percentage of Sidewalk Width Data, Rating 4

Figure 19 shows the percentage of sidewalk width data within each Census block with a width rating of 5. The highest quartile represents Census blocks with the highest percentage of sidewalk width data that are greater than 6 feet, which exceeds the recommended and minimum guidelines for accessible routes. The majority of sidewalk width data within the study area fell into this category, and thus the highest three quartiles within this map included blocks with greater than 90% sidewalk data with widths greater than 6 feet. The results indicate that the blocks with greater than 90% data points with width rating "5" were located along Peachtree Street from 8th Street to 15th Street and adjacent to 10th Street from Monroe Drive to Argonne Avenue.

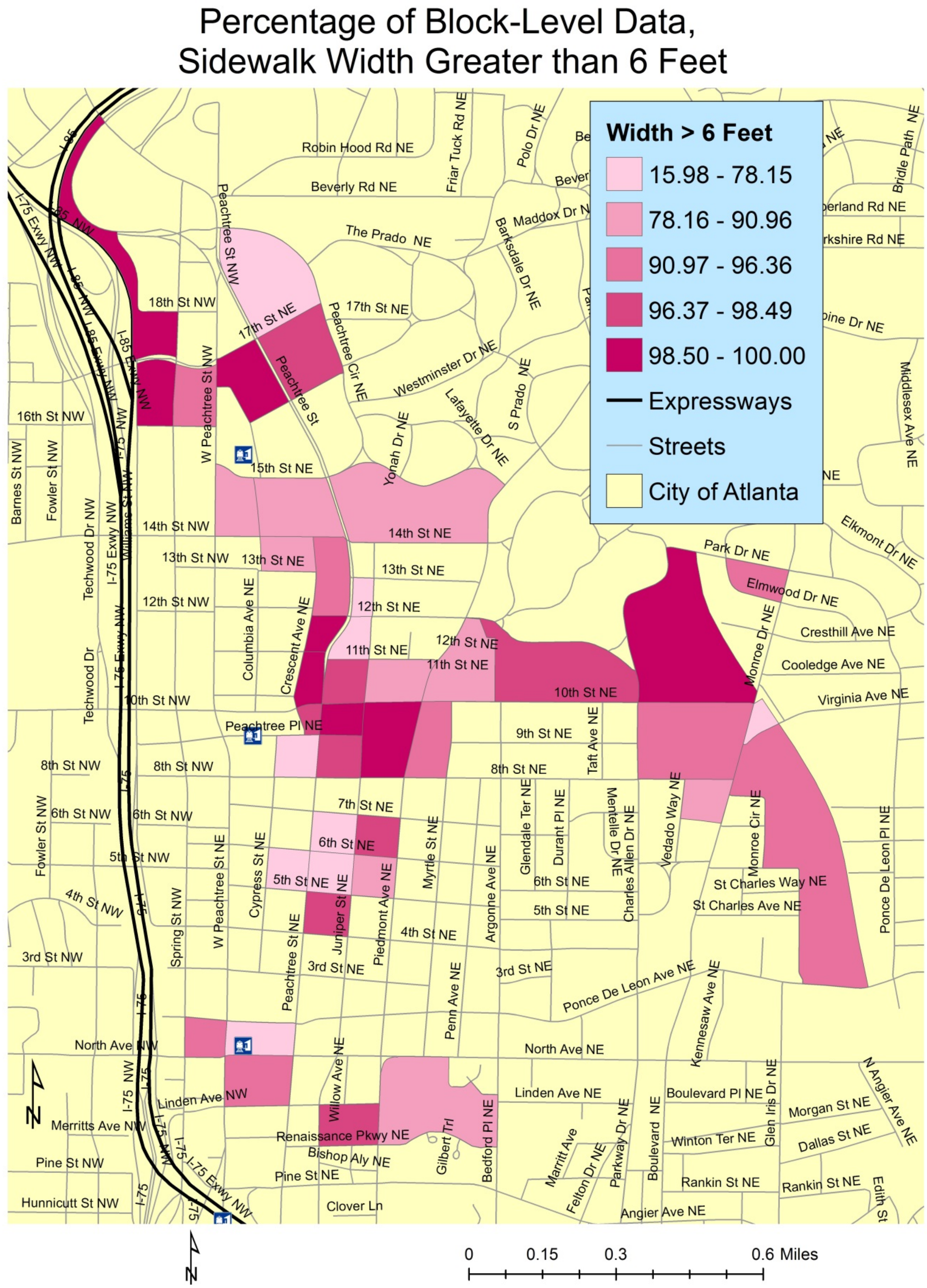

Figure 19: Percentage of Sidewalk Width Data, Rating 5

Figure 20 shows the percentage of GPS sidewalk data points within each Census block in the study area with width ratings from 1-3. The highest quartile represents Census blocks with the highest percentage of sidewalk data that are less than 5 feet in width. The results indicate that the blocks with the highest percentage of sidewalk width ratings from 1-3 were located within the Midtown residential neighborhood (from 5th Street to 7th Street specifically). These results also suggest a great degree of spatial variability in sidewalk width data, with blocks in the highest quartile located next to blocks with the lowest quartile throughout the study area.

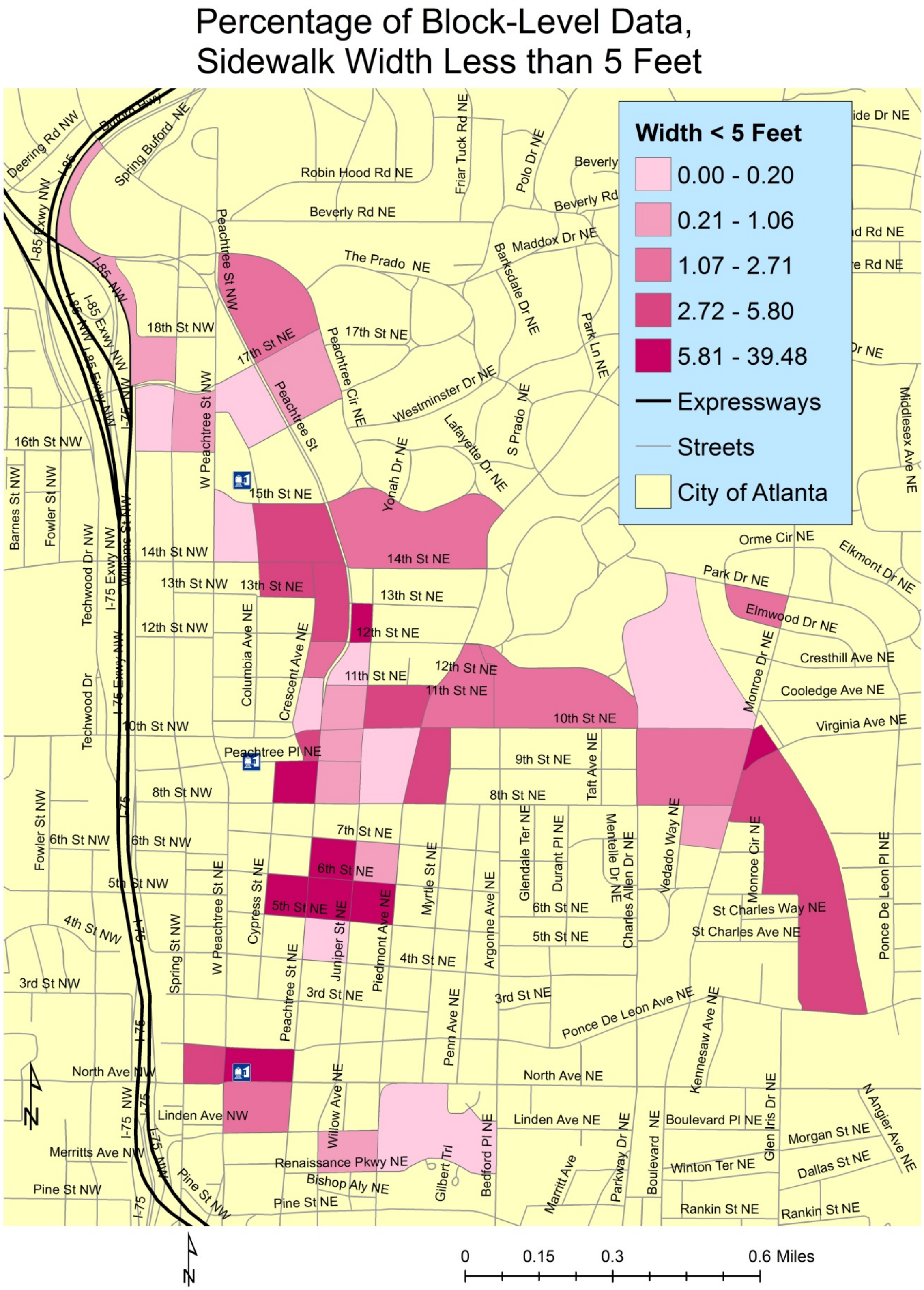

Figure 20: Percentage of Sidewalk Width Data, Rating 1-3

4.3 Weighted Rank-Order Prioritization

Rank-order prioritization results were mapped in ArcGIS for each pedestrian index by Census block within the study area. The ranking scores were symbolized by quantile. Although there were 42 Census blocks in total, several rank-order prioritization maps had a maximum ranking less than 42 due to identical values within the ranking calculation. For example, if two blocks were given the same rank sum value, both blocks were given identical composite rankings. For all ranking index thematic maps, the quantile of 1-9 represents the blocks that scored highest based on the variables and weightings included in the index. For the pedestrian potential index, an unweighted map was generated which weighted each variable equally (25%). Additionally, four maps were generated which weighted 60% a variable of interest and weighted the three remaining variables 13.33%, respectively.

For the pedestrian deficiency index, an unweighted map was generated that weighted each variable 50%, and two maps were generated which weighted 60% the variable of interest and weight by 40% the other remaining variable. Additionally, composite index rank-order prioritization results were mapped in ArcGIS, which was formed as a combined rank-order prioritization of the PPI and PDI results. An unweighted composite index map was generated that weighted each index equally (50%). Additionally, composite index maps were generated which weighted by 60% the PPI or PDI results.

4.3.1 Pedestrian Potential: Rank-Order Prioritization and Spatial Analysis

Figure 21 shows the rank-order prioritization results within the study area for the unweighted pedestrian potential index (PPI). The map indicates that Census blocks in the vicinity of the Midtown and North Avenue MARTA stations, as well as within the Midtown neighborhood near Tech Square would be prioritized based on pedestrian activity, demographic and population density data (weighted equally). Several blocks near Colony Square/Arts Center MARTA station were ranked within the second quartile of pedestrian prioritization, and Census blocks north of 15^{th} Street and east of Argonne Avenue ranked in the lowest quartile based on unweighted pedestrian potential indicators.

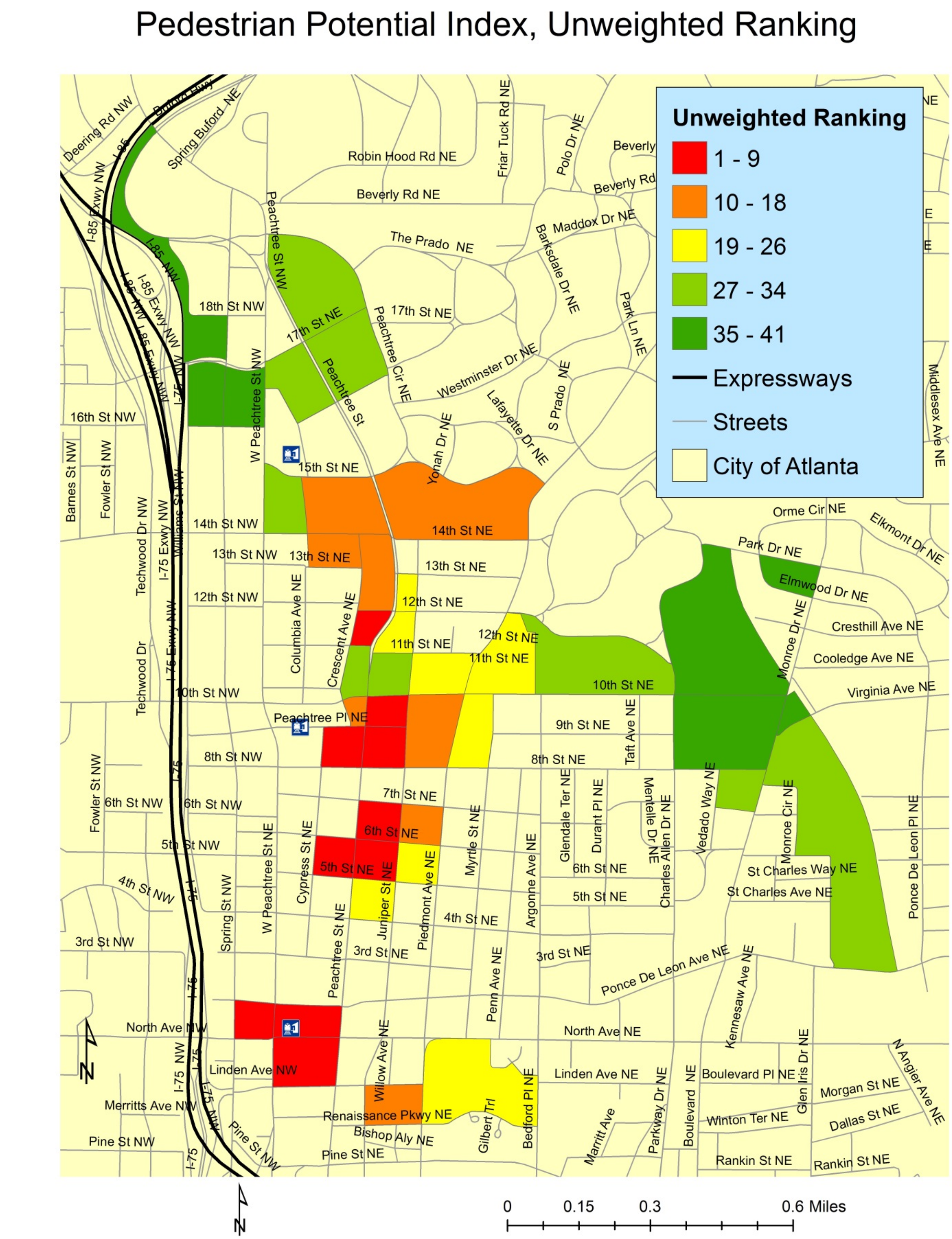

Figure 21: Pedestrian Potential Index Rank-Order Prioritization, Unweighted

Figure 22 shows the rank-order prioritization results within the study area for the pedestrian potential index (PPI) weighted by pedestrian activity. The map indicates that Census blocks in the vicinity of the Arts Center, Midtown and North Avenue MARTA stations would be highly prioritized using a pedestrian activity weighted PPI. On the map, a blue rectangular icon represents the location of MARTA rail stations. In contrast with the unweighted PPI results, the activity weighted results more highly prioritized blocks near the Arts Center station (in the first quartile instead of the second quartile). The least-prioritized blocks weighted by pedestrian activity data are located near the intersection of 10th Street and Monroe Drive and in the vicinity of Spring Street near the entrance to Interstate 85.

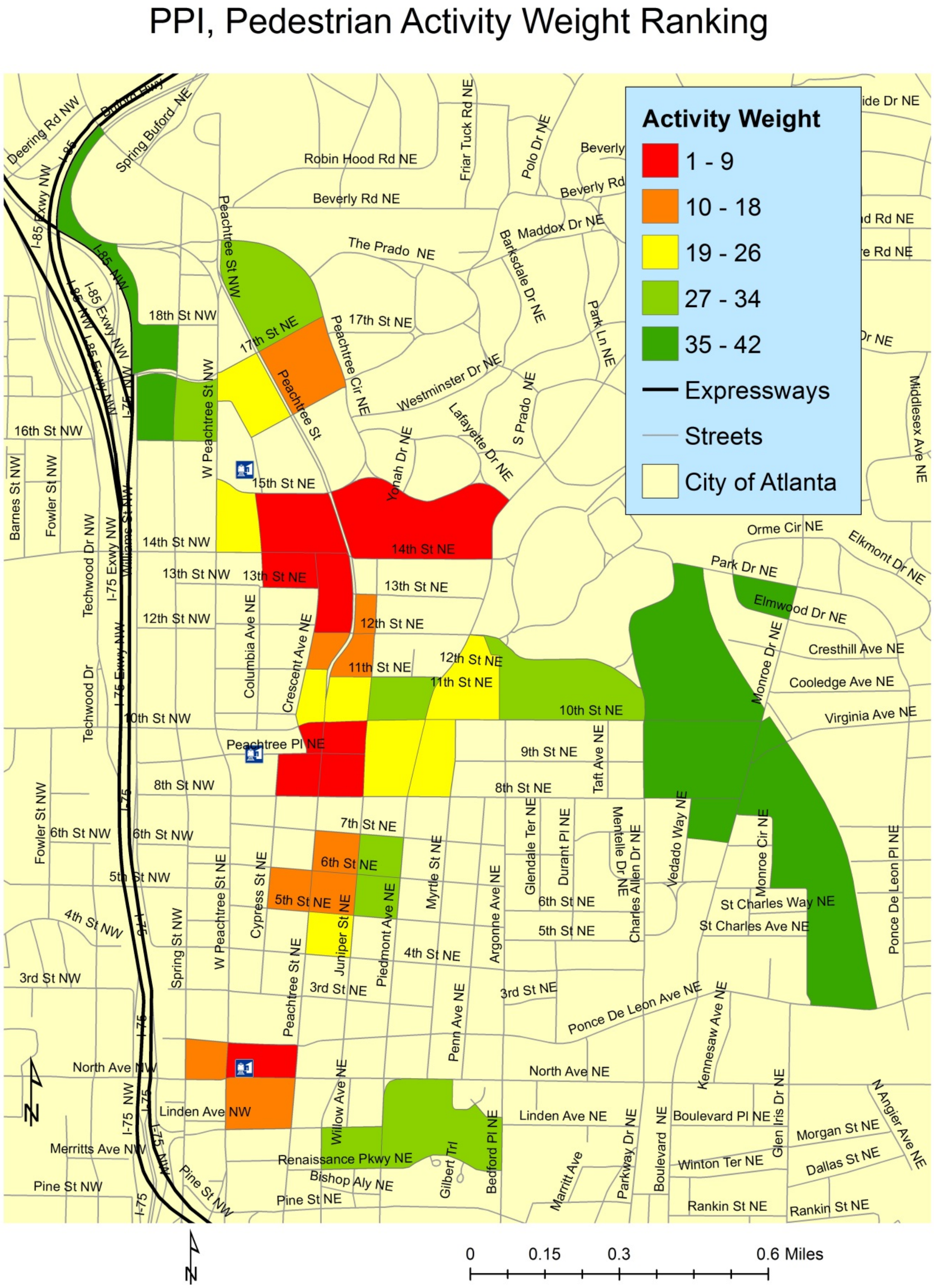

Figure 22: Pedestrian Potential Index Rank-Order Prioritization, Pedestrian Activity Weight

Figure 23 shows the rank-order prioritization results within the study area for the pedestrian potential index (PPI) weighted by commute mode share. The map indicates that Census blocks in the vicinity of the Midtown and North Avenue stations as well as near Tech Square would be highly prioritized using a mode share weighted index. In contrast with the activity weighted PPI results, the mode share weighted results did not prioritize blocks near the Arts Center station. Several blocks near the Arts Center/Colony Square were ranked in the third quartile. Similarly to the activity weighted index results, the least-prioritized blocks are located near the intersection of 10th Street and Monroe Drive and in the vicinity of Spring Street near the entrance to Interstate 85.

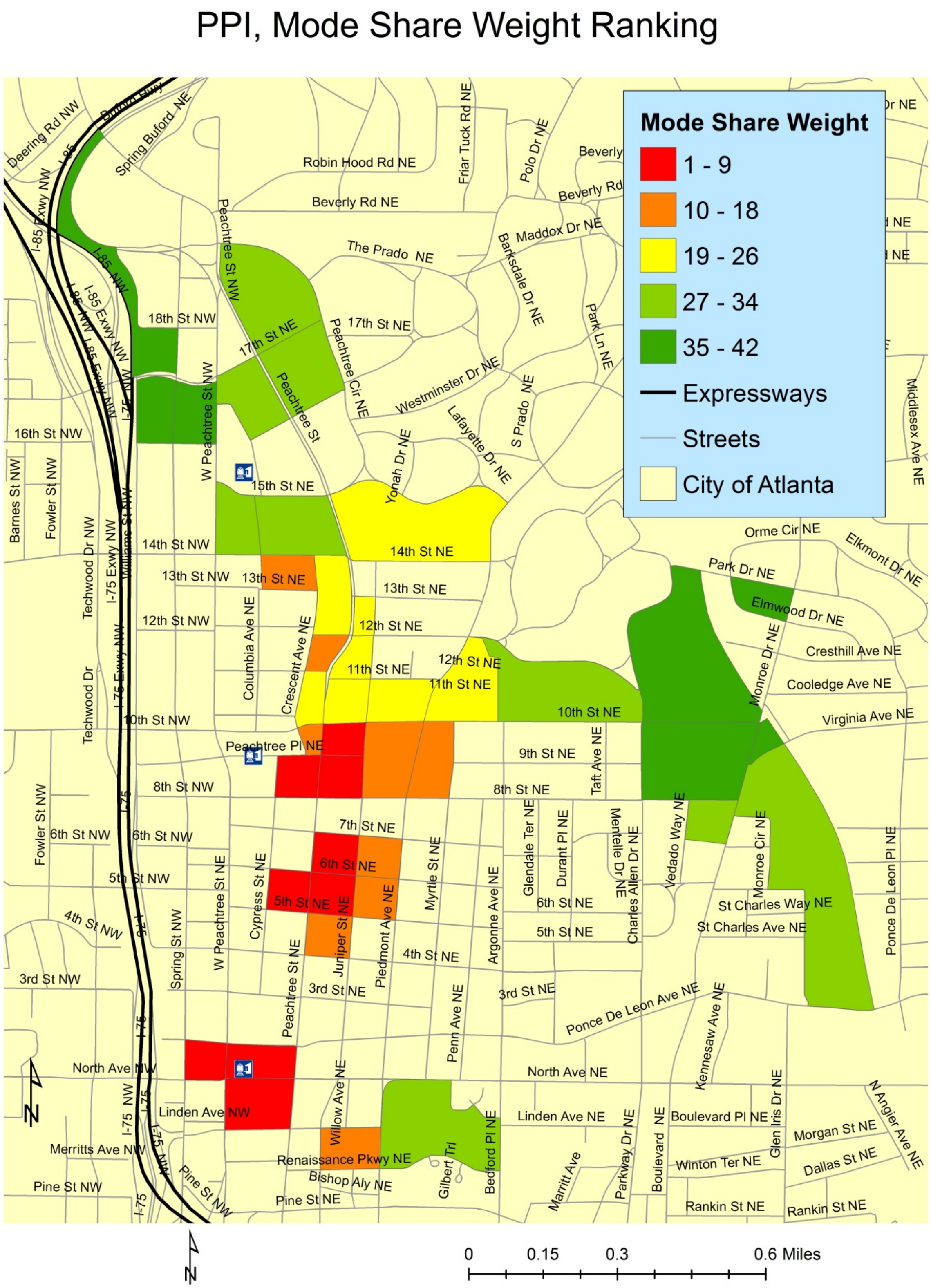

Figure 23: Pedestrian Potential Index Rank-Order Prioritization, Mode Share Weight

Figure 24 shows the rank-order prioritization results within the study area for the pedestrian potential index (PPI) weighted by population density. The density weighted results indicate variability in population density between adjacent blocks throughout the study area, with the exception of the Midtown residential area between 5th Street and 10th Street. In contrast with the activity weighted PPI results, the population density weighted results did not prioritize blocks near the Arts Center station. Similarly to the activity weighted and mode share weighted index results, the least-prioritized blocks are located near the intersection of 10th Street and Monroe Drive and in the vicinity of Spring Street near the entrance to I-85.

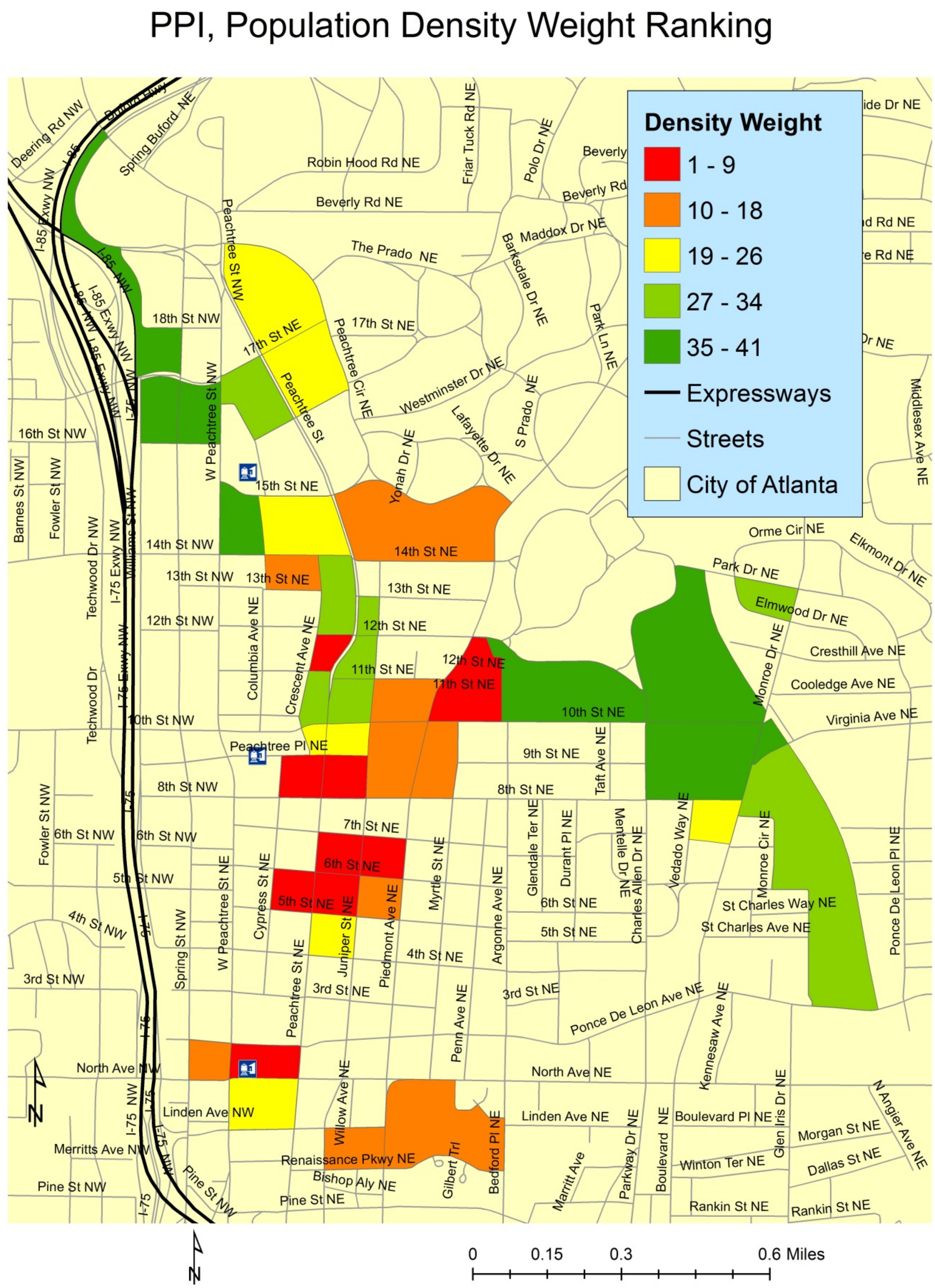

Figure 24: Pedestrian Potential Index Rank-Order Prioritization, Population Density Weight

Figure 25 shows the rank-order prioritization results within the study area for the pedestrian potential index (PPI) weighted by percentage of households with young children or mobility impairments. The map indicates that Census blocks in the vicinity of the Arts Center, Midtown and North Avenue stations as well as near Tech Square would be highly prioritized using a demographic (accessibility) weighted index. The density weighted results indicate variability between adjacent blocks throughout the study area, particularly between 10th Street and 15th Street. Similar to the activity weighted and mode share weighted index results, the least-prioritized blocks are located near the intersection of 10th Street and Monroe Drive and in the vicinity of Spring Street near the entrance to I-85.

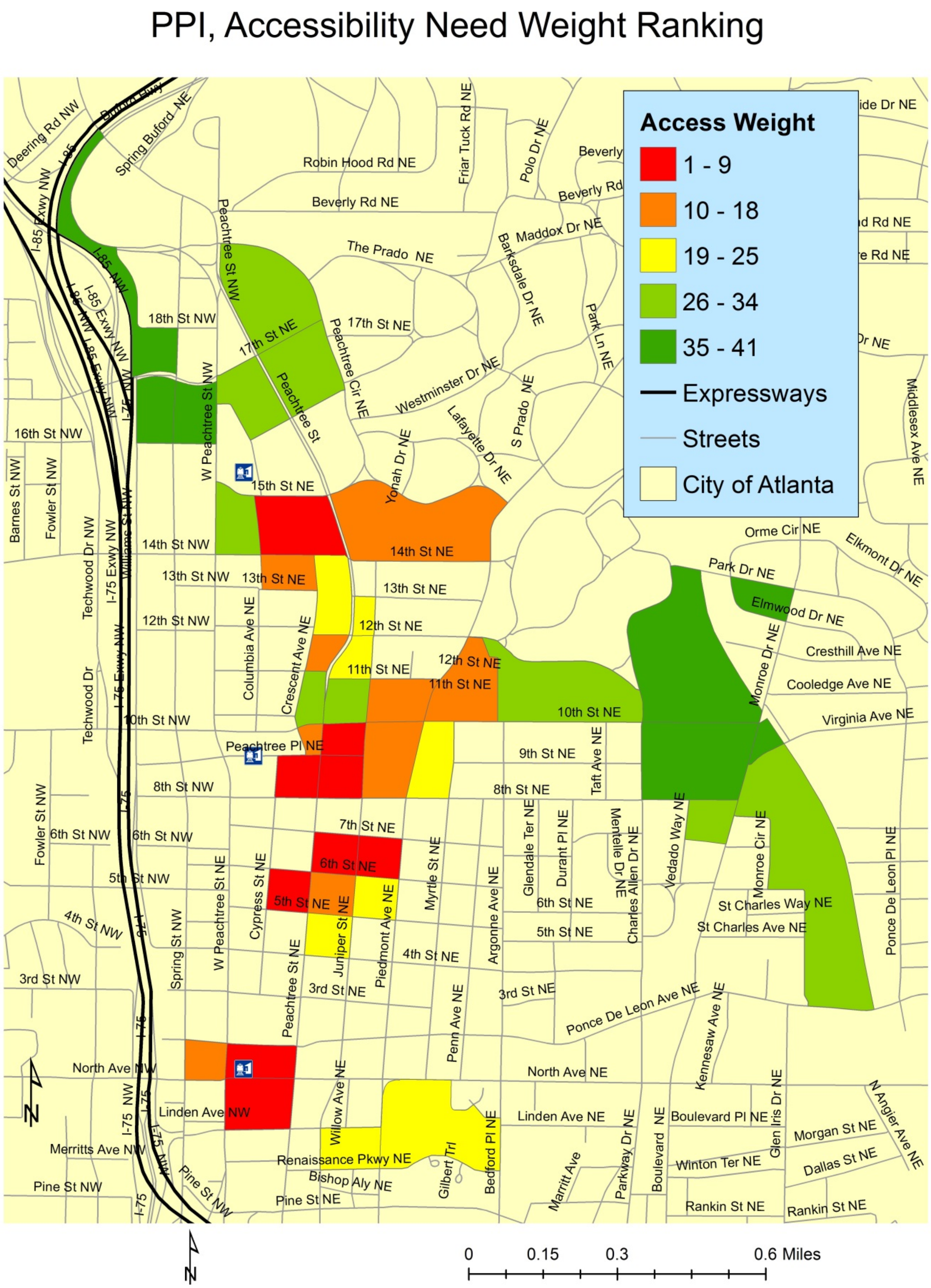

Figure 25: Pedestrian Potential Index Rank-Order Prioritization, Accessibility Weight

4.3.2 Pedestrian Deficiency: Rank-Order Prioritization and Spatial Analysis

Figure 26 shows the rank-order prioritization results within the study area for the unweighted pedestrian deficiency index (PDI). The map indicates that Census blocks in the vicinity of the Midtown and North Avenue MARTA stations and near the intersection of 10th Street and Monroe Drive would be highly prioritized based on sidewalk width and pedestrian crash data (weighted equally). Additionally, blocks within the Midtown neighborhood within walking distance of Tech Square were highly prioritized using the unweighted pedestrian deficiency index. These results contrast with the PPI mapping results, as blocks near Monroe Drive were prioritized in the fourth quartile within the unweighted pedestrian potential rank-order prioritization analysis.

Pedestrian Deficiency Index, Unweighted Ranking

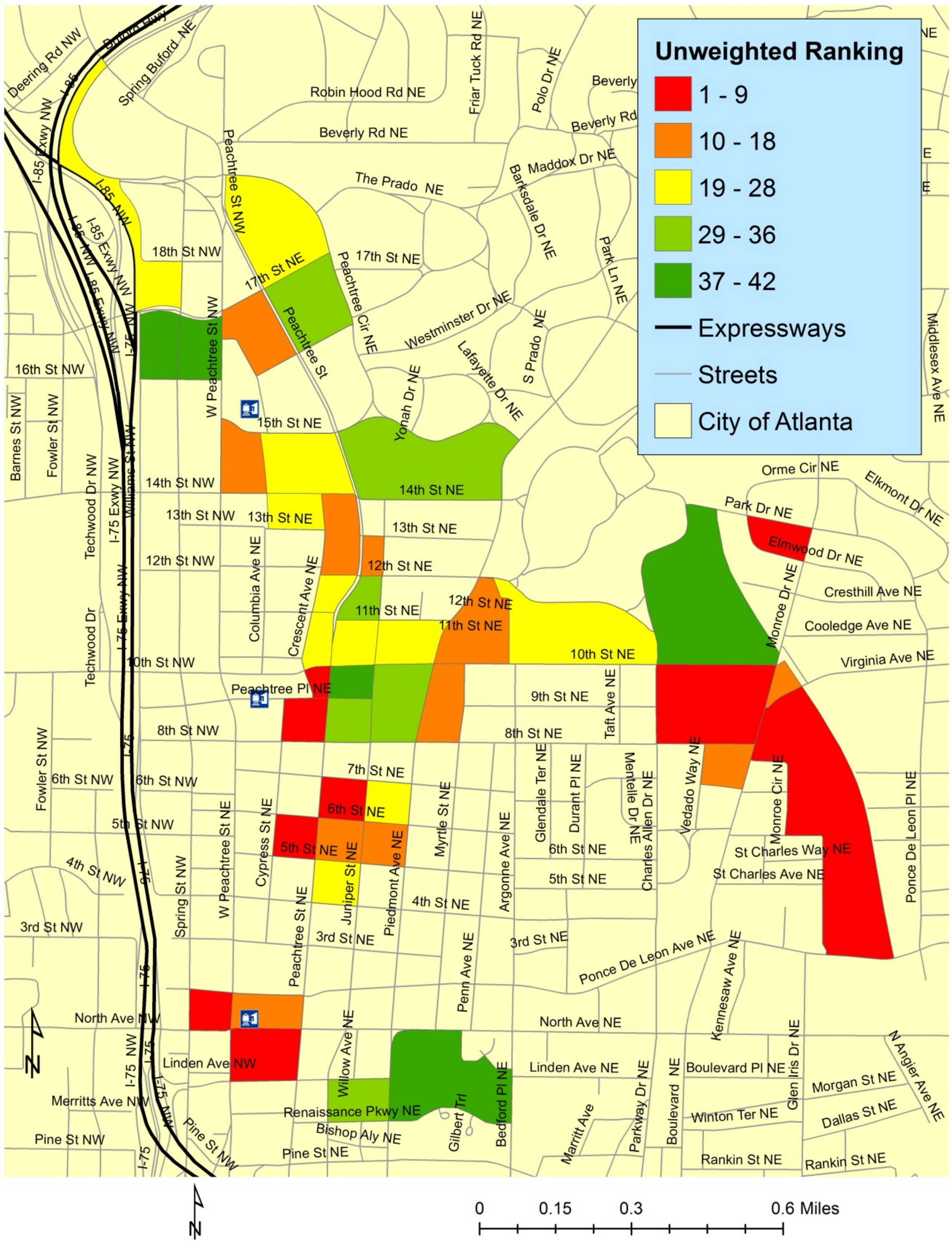

Figure 26: Pedestrian Deficiency Index Rank-Order Prioritization, Unweighted

Figure 27 shows the rank-order prioritization results within the study area for the pedestrian deficiency index (PDI) weighted by the percentage of sidewalk data with widths less than 5 feet. Similar to the unweighted index results, the map indicates that Census blocks in the vicinity of the Midtown and North Avenue MARTA stations and near the intersection of 10th Street and Monroe Drive would be highly prioritized using a sidewalk width weighted index. The sidewalk width weighted ranking results indicate spatial variability of sidewalk width data, with several blocks in the first quartile located adjacent to blocks in the fourth quartile.

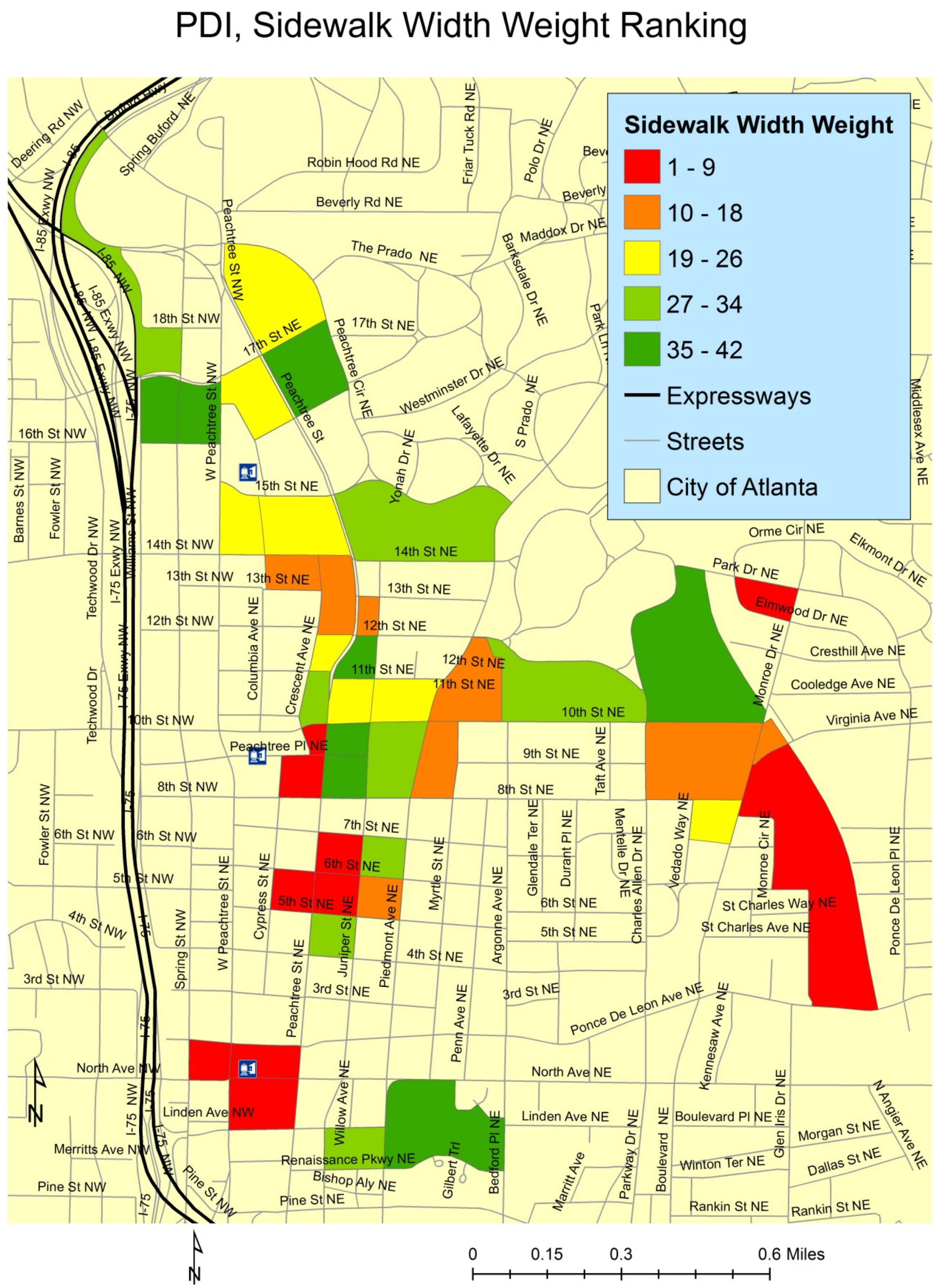

Figure 27: Pedestrian Deficiency Index Rank-Order Prioritization, Sidewalk Width Weight

Figure 28 shows the rank-order prioritization results within the study area for the pedestrian deficiency index (PDI) weighted by pedestrian crash density. Pedestrian crash events are correlated with high pedestrian activity as well as vehicle volume and speeds and can be mediated due to the effects of safety treatments. Therefore, it is important to consider these interactions when interpreting spatial patterns of pedestrian crash density. Similar to the unweighted index results, the map indicates that Census blocks in the vicinity of the North Avenue MARTA station and near the intersection of 10th Street and Monroe Drive would be highly prioritized using a crash density weighted index. However, the crash density weighting prioritizes the blocks along Monroe Drive more highly than the blocks within the Midtown residential neighborhood. Additionally, the block at Peachtree and 17th Street is ranked in the first quartile using the crash density weighting and in the third quartile using the sidewalk width weighting.

PDI, Pedestrian Crash Weight Ranking

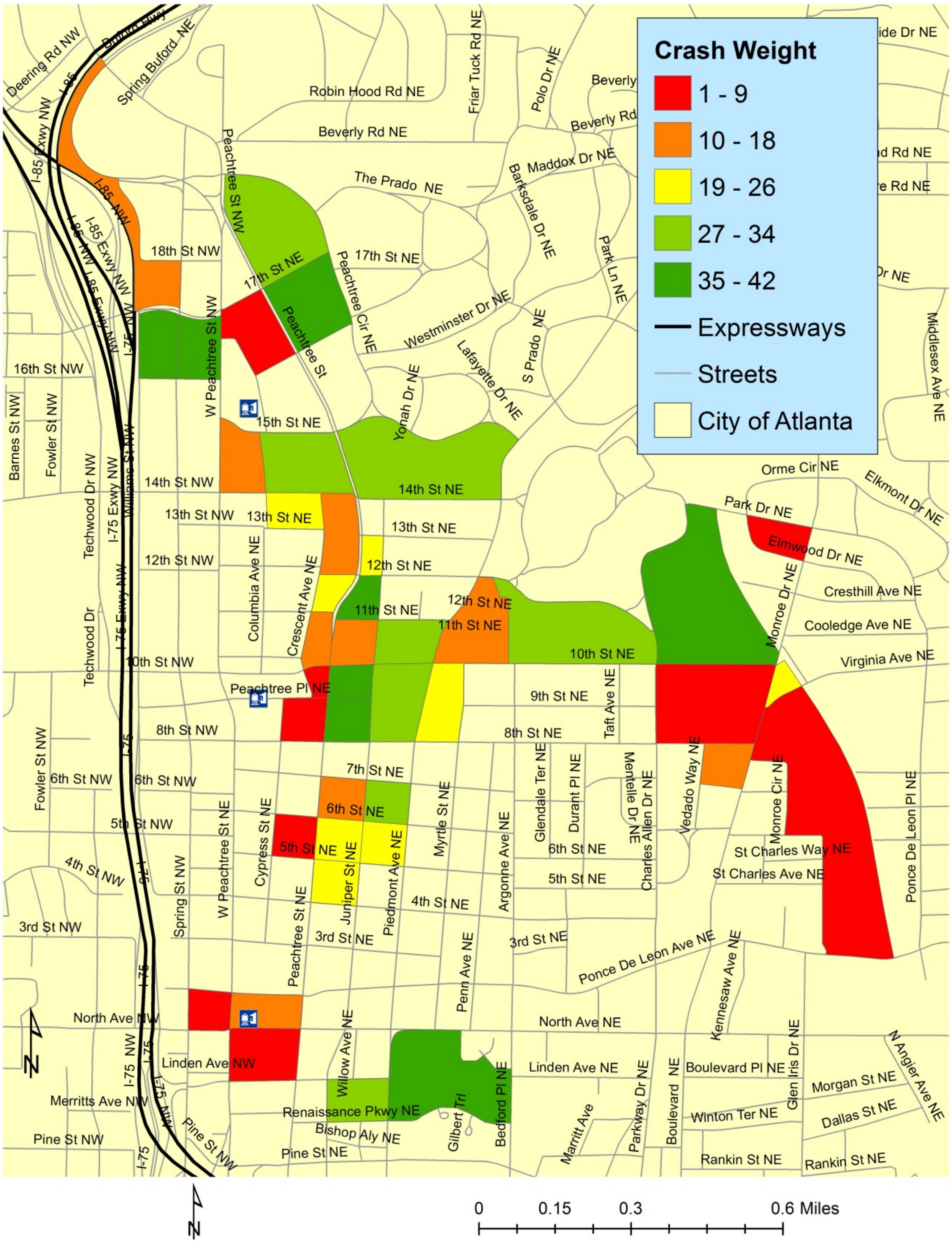

Figure 28: Pedestrian Deficiency Index Rank-Order Prioritization, Pedestrian Crash Density Weight

4.3.3 Composite Index: Rank-Order Prioritization and Spatial Analysis

Figure 29 shows the rank-order prioritization results within the study area for the unweighted composite pedestrian prioritization index. These index results indicate which Census blocks would be prioritized based on the greatest potential for pedestrian activity as well as the greatest existing deficiencies. The map indicates that Census blocks adjacent to the Midtown and North Avenue MARTA stations and along Peachtree Street (between 5^{th} and 7^{th} Street, and between 12^{th} and 14^{th} Street) should be prioritized for pedestrian improvements within the study area. Although the blocks along Monroe Drive were highly prioritized based on pedestrian deficiency indicators, the unweighted PPI results did not rank these blocks highly and therefore the composite index did not rate these blocks within the first quartile. Conversely, with a pedestrian deficiency weighting, the priority of these areas would increase.

Composite Index, Unweighted Ranking

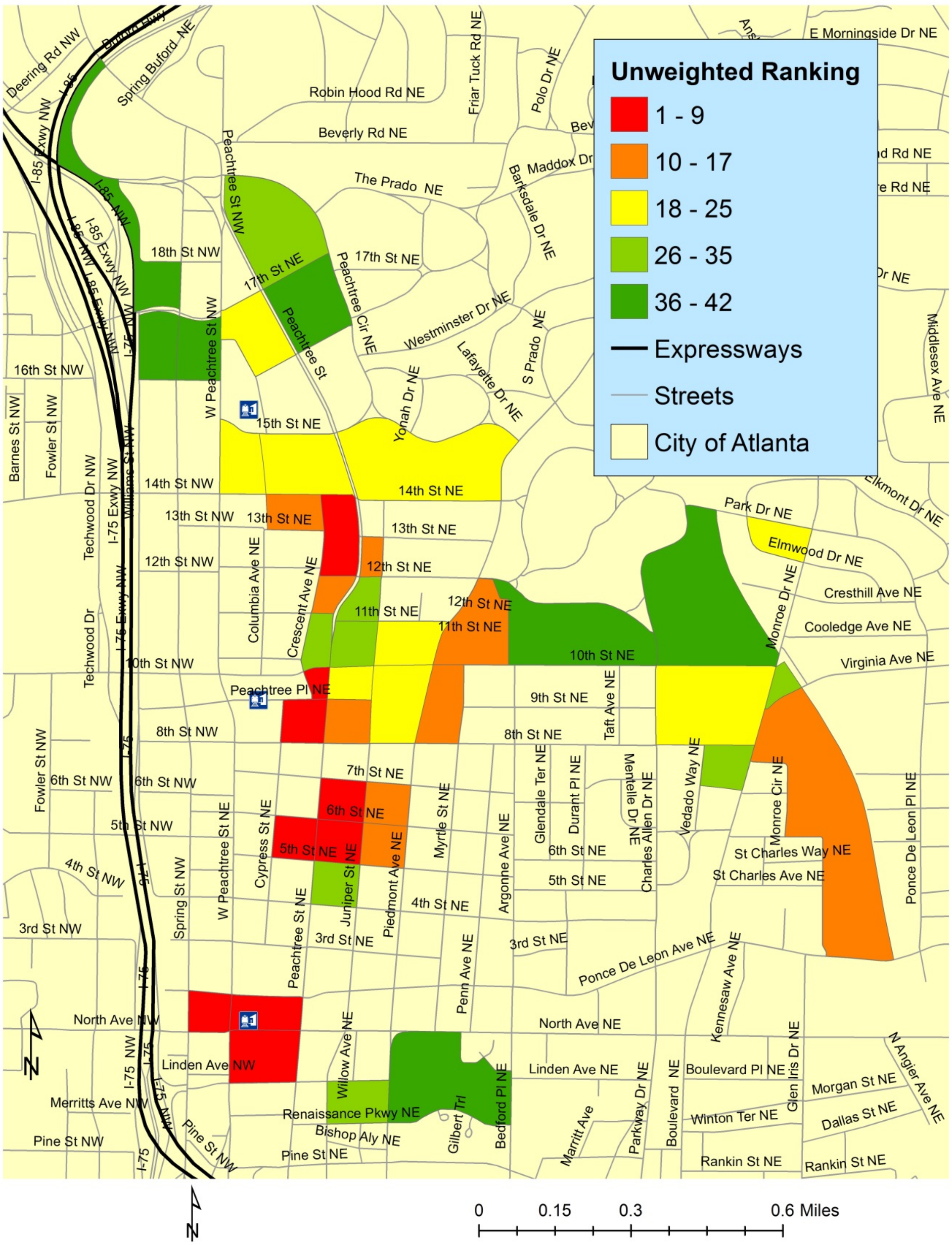

Figure 29: Composite Index Rank-Order Prioritization, Unweighted

Figure 30 shows the rank-order prioritization results within the study area for the composite prioritization index weighted by the pedestrian potential index (unweighted) results. The map indicates that Census blocks adjacent to the North Avenue and Midtown MARTA stations as well as along Peachtree Street near Tech Square should be highly prioritized for pedestrian investment weighted by the pedestrian potential index. When compared with the unweighted composite prioritization index results, the PPI weighted results increase the ranking of blocks within Midtown from 5th Street to 10th Street and decrease the ranking of blocks adjacent to Monroe Drive.

Composite Index, PPI Weight Ranking

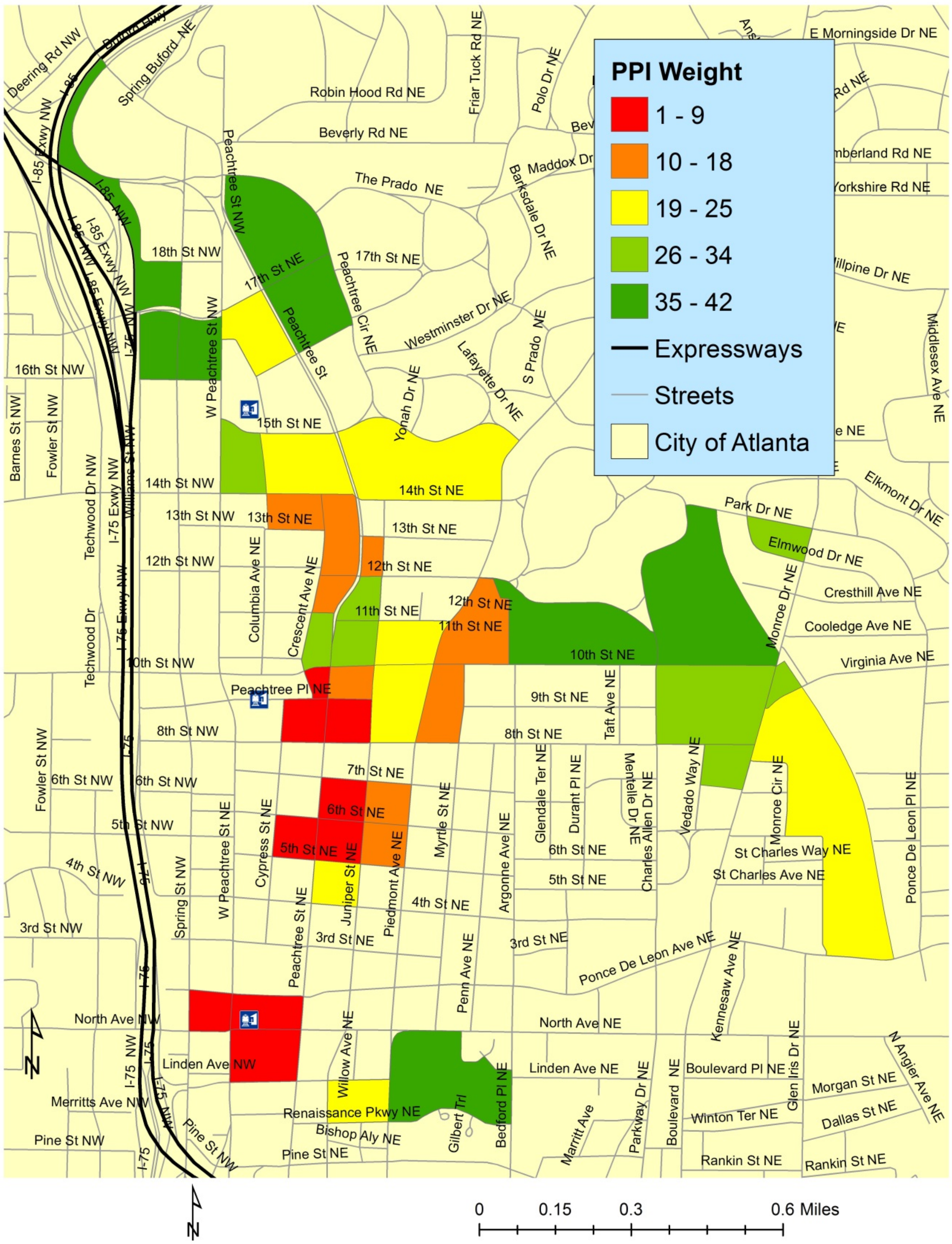

Figure 30: Composite Index Rank-Order Prioritization, PPI Weighting

Figure 31 shows the rank-order prioritization results within the study area for the composite prioritization index weighted by the pedestrian deficiency index (unweighted) results. Similar to the unweighted index results, the map indicates that Census blocks adjacent to the Midtown and North Avenue MARTA stations and along Peachtree Street (between 5^{th} and 7^{th} Street, and between 12^{th} and 14^{th} Street) should be prioritized for pedestrian improvements within the study area. When compared with the unweighted composite prioritization index results, the PDI weighted results increased the ranking of blocks near the intersection of Monroe Drive and 10^{th} Street, which were highly prioritized based on pedestrian crash density.

Composite Index, PDI Weight Ranking

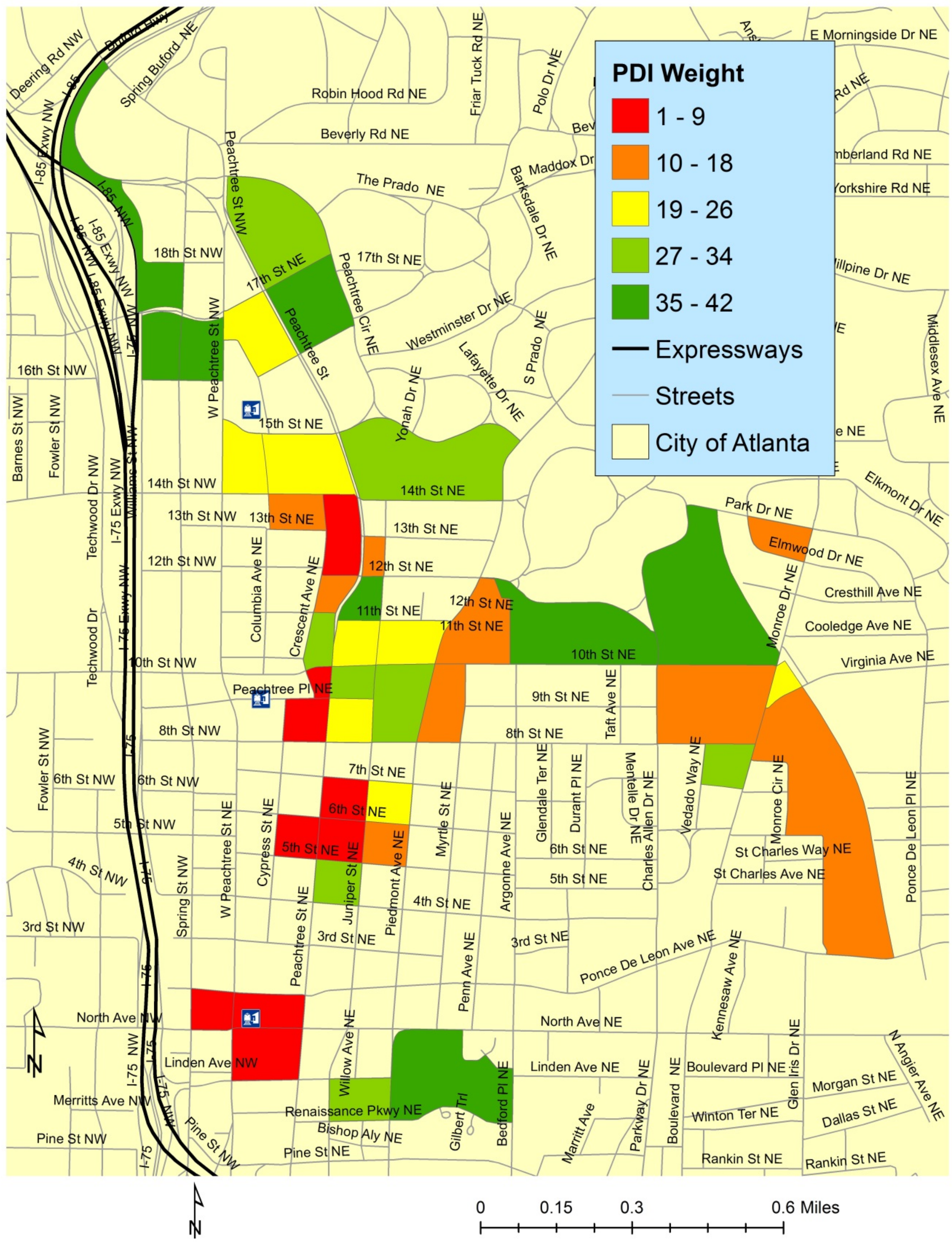

Figure 31: Composite Index Rank-Order Prioritization, PDI Weighting

CHAPTER 5

DISCUSSION

5.1 Pedestrian Indicator Data Analysis and Rank-Order Prioritization Results

5.1.1 MARTA Stations and Pedestrian Prioritization

Based on the individual PPI and PDI rank-order prioritization results, the blocks adjacent to the Midtown and North Avenue MARTA stations and near Technology Square were highly prioritized using the composite index. High-density residential housing, office buildings, and shopping surround these stations. Hence, the blocks surrounding these stations ranked highly based on pedestrian activity, mode share, and population density.

The pedestrian indicator data highlights the significance of North Avenue and Midtown MARTA stations, particularly for pedestrian potential indicators such as pedestrian activity, population density and commute mode share. Additionally, the commercial demographic data visually suggest a potential spatial relationship between blocks with higher percentages of persons with mobility impairments and presence of MARTA stations, which underlines the ADA and policy priority to ensure access to transit facilities for persons with disabilities. However, it is difficult to interpret significance of these data given the low number of households per block identified by the private demographic data. For example, many blocks within the study area had zero households with mobility impairments or young children, and the maximum number of these households within a single block in the study area was two. Therefore, these data may be more conducive to macro-scale spatial analysis and prioritization such as regional planning prioritization. Alternatively, marketing data could be supplemented by other data sources in order to prioritize areas with high percentages of persons with disabilities, such as handicapped parking permit records, enrollment in paratransit services or locations of assisted living facilities or senior centers.

Based on pedestrian indicator data, the Arts Center station area experiences high weekday pedestrian activity but would not be prioritized based upon population density nor based upon non-automobile commute mode share. The existing land use within this subarea suggests that the weekday pedestrian activity is likely due to office workers and may not extend to population density or mode commute share. However, overall mode share for all trips in this zone may be a factor to consider. Additionally, blocks within Midtown with primarily commercial or office uses will not rank highly based on population-dependent metrics (such as density and mode share), which is demonstrated by the blocks with higher tract-level commute mode share but with a population density of zero. Based on the rank-order prioritization results, the Colony Square area ranked highly in the activity-weighted index, but ranked lower in other weightings and in unweighted composite index results due to the lower rankings in other pedestrian potential and deficiency indicators.

5.1.2 Monroe Drive: Deficiency vs. Potential

The pedestrian crash data suggest that blocks along high volume and/or higher speed roadways are correlated with higher pedestrian crash densities. In addition to roadway characteristics and infrastructure safety, the number of pedestrians can increase exposures to traffic crashes. Thus, pedestrian crash densities along Peachtree Street may also relate to the high weekday pedestrian activity along that corridor.

As discussed previously, the blocks along Monroe Drive near Piedmont Park received higher prioritization using the PDI weighted ranking and lower prioritization using the PPI weighting. Based on the PPI rank-order prioritization results, blocks near Monroe Drive and Spring Street near I-75 were less prioritized based on pedestrian “demand” indicators. Additionally, these blocks also ranked low on population density and commute mode share indicators due to lower housing/population values. For example, several blocks along 10th Street actually correspond to locations within Piedmont Park and therefore impact the average score on population-dependent measures.

In the PDI prioritization results, blocks near Piedmont Park/Monroe Drive were prioritized due to relatively high pedestrian crash density and sidewalk width deficiency rankings. These results indicate that although some blocks were prioritized by both pedestrian potential and deficiency rankings, areas may be prioritized within one index but not the other. The low composite ratings along Monroe Drive raise the issue of directionality in the relationship between infrastructure condition, safety and pedestrian travel demand. For example, the lack of pedestrian activity in certain areas may be related to the lack of infrastructure and safety concerns in addition to other built environment and demographic variables. Similarly, high pedestrian activity may be an indicator of high quality facilities. In the case of Monroe Drive and 10th Street, a multi-use path (BeltLine Eastside Trail) opened and a new pedestrian crossing was installed only a few months before the collection of pedestrian count data utilized for this analysis. It is likely that these infrastructure changes will affect long-term pedestrian activity patterns at this location, which may need to be reflected in future pedestrian planning analyses and in ongoing assessment.

5.1.3 Influence of Zoning and Infrastructure Capital Improvements Supporting Walking

The majority of sidewalk width data within this particular study area exceeded accessibility width guidelines (rating of "5"). Further, a substantial number of cases had sidewalk widths greater than 10 feet, with a group of cases with sidewalk width data greater than 20 feet. This is not the case for much of Atlanta. The blocks within the study area with the highest percentage of data greater than 6 feet were found along the Peachtree Street corridor from 8th Street to 15th Street. This trend is largely due to the initiatives of Midtown Alliance, a community improvement district that has spearheaded capital improvement and transit-supportive land use planning and urban design guidelines within Midtown.

For example, the Special Public Interest (SPI-16) zoning overlay district within the Midtown commercial area includes supplemental requirements for sidewalk width. Specifically, districts along the Peachtree Street corridor are required to have a 15 feet "pedestrian clear zone" in addition to any space for building frontage, landscaping and street furniture (Midtown Alliance, 2013b). Since its formation in 2001, Midtown Alliance has undergone many streetscape projects and has constructed over 14 miles of new sidewalks (Midtown Alliance, 2013c, see Figure 32).

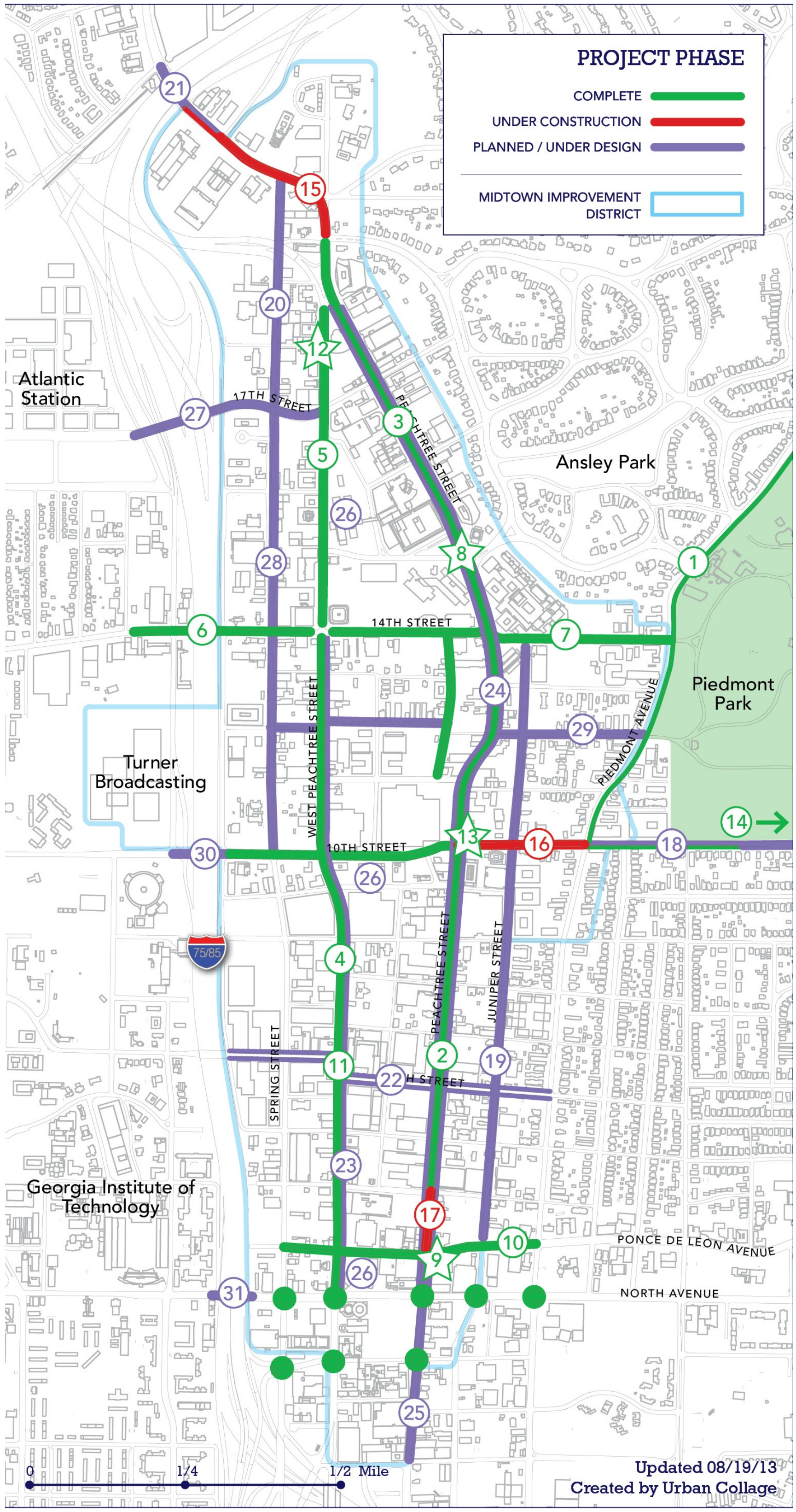

Figure 32: Streetscape Projects Constructed by Midtown Alliance

5.1.4 Midtown Residential: The Spatial Variability of Sidewalk Width Deficiency

Within the study area, the blocks near the Technology Square mixed-use development (at 5th Street between West Peachtree Street and Williams Street) ranked highly in terms of pedestrian potential as well as deficiencies in sidewalk condition. Specifically, these blocks were highly prioritized based on population density; commute mode share and sidewalk width deficiency (and less prioritized based on pedestrian crash density and pedestrian activity). These data may suggest the effect of Georgia Tech students, of which approximately 22,000 live within the “Midtown core” (Midtown Alliance, 2013d). According to the 2011 Georgia Tech Commute Survey, 9.9% of students walk to campus (Georgia Institute of Technology, 2011), which suggests that areas with student housing and access points to campus or to the Tech Trolley may have additional need for infrastructure that supports walking.

The Midtown residential area south of 10th Street had highest percentage of low-rated sidewalk width data. As indicated by Figure 32, this subarea within Midtown lies outside of the SPI-16 zoning district and has not benefited from recent streetscape projects. When compared with the new construction along the “Midtown Mile” within the Peachtree Street corridor, the neighborhood also contains older housing stock. The age of the Midtown residential area may contribute to the presence of sidewalk deficiencies, in addition to the conversion of single-family homes to apartments within this section of the neighborhood. This trend is indicated by the population density data, as many blocks ranked highly based on population density despite the presence of many older single-family homes. Both the age of the neighborhood and population density suggests that many existing sidewalks may be aging or deteriorated and less likely to be maintained, given that the legal responsibility for sidewalk maintenance rests on the adjacent property owner (see Chapter 2). Future analyses should incorporate parcel-level land use data in order to test the assumption that housing age and condition may be correlated with sidewalk maintenance and overall quality.

The sidewalk width weighted PDI index results indicate a lack of consistency spatially in terms of block-level rankings. As noted in Chapter 4, several Census blocks within this subarea were ranked highly for sidewalk width deficiency and located next to blocks that were ranked low for sidewalk deficiency. However, it is important to note that even the highest ranked blocks did not have a majority of data points with sidewalk width measurements less than five feet. Based on this micro-scale prioritization analysis, more geographically extensive sidewalk width data may be needed to assess the extent and impact of this observed spatial variability. Given the legal framework of sidewalk maintenance within the City of Atlanta, where adjacent property owners are deemed responsible for sidewalk repair, it is plausible that sidewalk quality may vary considerably even from parcel to parcel within the same block.

5.2 Application of Prioritization Framework using Quantitative Sidewalk Data

As described in Chapter 2, recent literature and practice recognizes that the lack of pedestrian-scale infrastructure condition data is a barrier to fine-grained analyses and ADA compliance and implementation. This research proposes using a set of block-level pedestrian potential and deficiency indicators to prioritize planning investments within a subarea of Midtown, Atlanta (GA), combining available data sources with app-collected sidewalk (width) data. The results of these analyses indicate that blocks near MARTA rail stations (particularly North Avenue and Midtown) and Georgia Tech/Tech Square should be prioritized for pedestrian investments. These areas were highly prioritized due to increased pedestrian activity near transit stops and education/employment centers, high population density as well as pockets of poor infrastructure condition. Further refinements are needed in order to extend the application of this methodology to larger geographic scales, including refinements in data analysis, expansion of geographic scope and the development of ongoing institutions to assess and prioritize pedestrian projects.

5.2.1. Data Considerations

As noted in Chapter 3, American Community Survey data for transportation mode share were only available at the Census tract level, which was aggregated to the Census block for use in block-level analyses. Although this was the most refined detail available at this scale, using aggregated spatial data to represent smaller scale units introduces potential inaccuracies and difficulties in interpreting results; data representing an entire Census tract may not accurately describe the local population of an individual block. In future research, travel behavior surveys may provide a more accurate data source for detailed travel behavior data. However, standard travel behavior surveys (such as the 10,000-household regional household travel survey conducted by the Atlanta Regional Commission) will still present challenges when applied to micro-level analyses due to the small sample size associated with individual the neighborhood or block level units, particularly in the case of pedestrian trips.

The pedestrian count data utilized for this analysis were collected during three peak periods during a single weekday in 2011. One shortcoming of these data source was the lack of validation; count data over multiple days would help ensure the validity of observed travel patterns. Longer count periods would also improve level of detail of this data source and could provide count data for evenings as well as weekdays; the current use of weekday counts may tend to emphasize pedestrian travel by office workers and students. Additionally, pedestrian counts were only recorded at select intersections determined by Midtown Alliance, and thus many blocks did not have count data for its entire geographic area, and mid-block pedestrian activity was not included in this dataset.

As noted previously, the commercial marketing data used to determine the households with mobility impairments and young children contained relative few records at the Census block level (from zero to two households per block). Additionally, the indicator used for this analysis assumed that the number of households within the marketing database was comparable to the number of housing units per block according to Census data. The total number of households within the marketing database on the Census block level was not available from the current dataset. Future studies should consider using more comprehensive parcel level land use data and other demographic variables associated with households and businesses. However, data indicating the presence of mobility access issues within a small geographic area are not currently available from the Census Bureau and such data are needed to consider the usage of pedestrian facilities by persons with disabilities when planning repairs and improvements.

This research utilized app-collected GPS data linked to sidewalk width attributes for the first time within a planning application. As described in Chapter 2, data points coded as "no sidewalk" were removed from consideration in this analysis. Therefore, the data points with "no sidewalk" were observed as gaps between GPS points along a sidewalk segment. Future analyses should incorporate lack of sidewalks in the indices to improve the level of detail and accuracy in applying sidewalk data to prioritization. A relative scoring mechanism will need to be derived to include lack of infrastructure and properly weight this value against poor quality infrastructure. Given that there is likely some width transition between "no sidewalk" and an existing sidewalk, data points with very low sidewalk widths (i.e. less than two feet in width) may denote a subarea with no sidewalk. Scoring "no sidewalks" as a value of 1 might be the best short term approach to integrating this element into the index.

Due to the presence of many high-rise buildings, GPS accuracy issues were noted during mapping and cleaning of raw GPS data in preparation for analysis. Although it was assumed that GPS inaccuracies would not impact the validity of block-level metrics, sidewalk segment or point-based analysis should consider implementing a methodology to handle any problems with GPS accuracy when determining the actual spatial location of GPS-encoded sidewalk quality data, if the GPS accuracy is deemed to affect scoring results.

5.2.2. Methodological Considerations: Objective Built Environment Data

Researchers and practitioners recognize both the time and resource intensive nature of audit instruments and in-person observation for the purposes of built environment data collection. The state of the practice also recognizes the potential for technologies such as GIS, PDAs and mobile applications to improve the cost-effectiveness of built environment and travel behavior data collection. The Sidewalk Sentry sidewalk data collection and assessment system reduces the time needed for field data collection as well as data collector training. When compared with a walkability audit instrument that may require urban design or engineering expertise to assess the built environment, an automated data collection system may improve cost-effectiveness of data collection due to the decreased need for staff time as well as expert training. However, automated systems utilizing advanced technologies and field data collection do require additional time and resources for system development, calibration as well as data cleaning and preparation.

Brownson, et al., (2009) noted several potential issues with the use of GIS-based built environment measures that are relevant to this research. One challenge in the application of GIS-based methodologies is that the time period of data collection may differ from the time period of "outcome measurement." For example, the data sources utilized in this analysis would indicate a lack of "pedestrian potential" near the intersection of 10th Street and Monroe Drive. However, transportation infrastructure and travel behavior changes have occurred since the data collection years (2013 for the pedestrian activity data source), which may challenge this outcome and prioritization result.

Although the pedestrian activity data was collected after the opening of the BeltLine Eastside Trail, it is plausible that pedestrian activity has increased since March, 2013 due to the increasing popularity over time and adjustment to pedestrian safety improvements. Given that existing conditions and travel behavior do not always accurately predict future trends, one must use caution when applying future prioritization and planning decisions based on existing data sources. Ongoing infrastructure and activity monitoring is necessary in order for planning processes and decision support tools to be fully responsive to changes due to new infrastructure and travel behavior patterns. For example, it is recommended that transportation improvements be digitized in a GIS-based asset management tool in order to analyze the effect of new transportation projects and track the condition of existing infrastructure assets.

The Census block was selected as the geographic scale of analysis to assess pedestrian indicators on a relatively micro-scale. Additionally, the use of Census geography allowed the researcher to incorporate Census demographic data. However, the Census block geometry depends on the existing road network and may not accurately reflect a reasonable walking distance in all cases. In order to operationalize a pedestrian prioritization framework, it will be necessary to evaluate individual sidewalk segments or parcels for infrastructure repair or replacement. It may be useful to first identify the specific Census blocks within a larger area for further consideration within planning and prioritization, and in the future utilize fine-grained sidewalk quality data to pinpoint specific locations requiring ADA improvements.

5.3 Future Research

This exploratory analysis has proposed and tested a methodology for pedestrian prioritization utilizing objective sidewalk width data in combination with other data sources. The results of this analysis identified patterns in pedestrian potential and deficiency rankings based on a subarea within Midtown, Atlanta. Future research is needed in order to enhance the application of app-collected sidewalk data within this prioritization framework within planning and prioritization processes on local and regional scales. Refinements in data analysis will enable researchers to test the applicability of the exploratory analysis results, add further indicators and expand the geographic scope of the sidewalk quality dataset.

5.3.1 Refined Sidewalk Quality Analysis

To conduct sidewalk segment-level sidewalk quality analyses, future research should convert sidewalk data encoded GPS points to a distance-based GIS feature. This would allow researchers to rate individual segments within a single block, as well as calculate percentage-based sidewalk quality indicators at a more detailed level than the Census block. However, one would have to either assign "gaps" the same value as the preceding sidewalk width value, or interpolate between the "start" and "end" point-based value to assign data to spatial locations where no data is found. To do this accurately, future research should incorporate information on

GPS points with data but indicating “no sidewalk.” It is likely that the “no sidewalk” GPS points can be included within this distance-based evaluation system.

The results of the pedestrian deficiency index rank-order prioritization suggest that sidewalk width deficiencies may be variable even within a small spatial area (e.g., two to four blocks). It is recommended that future research test the spatial variability of sidewalk width data using spatial statistics in order to test if sidewalk deficiency is randomly distributed. This statistical analysis should be conducted both within neighborhoods and jurisdiction-wide in further analysis of sidewalk quality trends. Assuming that sidewalk deficiency is not randomly distributed, future research should also conduct cluster or hotspot spatial analysis to identify patterns in sidewalk quality within a large geographic area (i.e., the core areas within the City of Atlanta that were prioritized for field data collection (see Chapter 2).

For the purposes of this exploratory prioritization analysis, sidewalk width was utilized as a proxy for sidewalk infrastructure condition. Although sidewalk width or presence has been used thus in prior studies, a more comprehensive evaluation framework should incorporate other sidewalk quality and accessibility metrics such as the presence of obstructions, density of pavement cracks and the presence of curb ramps. For example, sidewalk segments with “acceptable” widths may be inaccessible for persons with disabilities due to deteriorated pavement condition or the absence of a curb ramp at pedestrian crossings. Currently, researchers at Georgia Tech collect data using Sidewalk Sentry on additional sidewalk quality metrics:

- Surface roughness
- Pavement crack density
- Presence of obstructions
- Curb ramp absence

The metrics outlined above should be incorporated into applications of the pedestrian prioritization framework in the future (Grossman et al., 2013). Ideally, these metrics would form a composite sidewalk quality index to be used in combination with other demographic, travel behavior and built environment variables. Although existing data sources and automatically-collected field data provide a baseline for pedestrian project prioritization, prioritization results should be further compared with user experience and pedestrian comfort measures. For example, index prioritization results could be weighted depending on the importance of various indicators for persons with disabilities.

5.3.2 Application to Planning and Prioritization Processes

To apply the pedestrian prioritization framework outlined in this thesis within existing planning processes, it will be necessary to conduct analyses that test the incorporation of indices over a much larger geographic area (i.e., for all Census blocks within the City of Atlanta). However, larger scale analyses may require additional data collection or may require the removal of specific indicators from consideration. Pedestrian activity data are simply not available for every intersection within the City of Atlanta. Thus, other data sources may be needed to forecast pedestrian demand over a large area. Transit ridership data (boarding and alighting) and pedestrian trip data from the ARC regional travel demand model, could provide a proxy for pedestrian demand in the absence of pedestrian activity data on a large scale. However, these data sources may not include sufficient sample size or geographic information to aggregate pedestrian trips or transit trips to the level of blocks or sidewalk segments.

For the purposes of this research, different index and indicator weightings were utilized in order to compare the effects of each indicator as well as the effects of the "potential" and "deficiency" indices within a composite index rank-order prioritization framework. To incorporate the pedestrian prioritization framework into the planning processes, variable and index weightings should be adjusted to reflect stakeholder and policy priorities. For example, it is likely that an agency conducting an ADA transition plan would weight sidewalk deficiency variables and residential locations of disabled community members more highly than other pedestrian potential variables. Additionally, city and regional agencies might place high importance on prioritizing investments to generate maximum pedestrian demand, while state agencies might prioritize pedestrian safety indicators.

Finally, it is recommended that local, regional and state agencies integrate pedestrian prioritization and suitability measures into agency-wide performance measures as well as project selection criteria. Future research should consider approaches to operationalize sidewalk quality and pedestrian activity metrics within ongoing project prioritization and infrastructure condition analyses. Expanding the geographic scope of analysis and adjusting variable weightings to suit agency priorities may apply the composite prioritization index proposed and tested by this research applied to prioritize areas for pedestrian project investments.

CHAPTER 6

CONCLUSION

Recent technological advances present an opportunity to incorporate fine-grained pedestrian infrastructure data into planning and prioritization processes that seek to assess the suitability of areas for pedestrian improvements. Thus far, the lack of data on sidewalk presence and condition has been recognized as a barrier in pedestrian prioritization analyses as well as ADA accessibility evaluation and compliance. To address this gap in research and practice, researchers at Georgia Tech have developed and tested a system that utilizes an Android App to collect video, accelerometer, gyroscope and GPS data to assess sidewalk condition based on federal accessibility guidelines and industry best practices.

This research presents and tests a proposed methodology to prioritize Census blocks for pedestrian investment, using a combination of existing data sources and app-collected sidewalk width data. These data were cleaned, prepared and aggregated to the Census block spatial scale for use in GIS-based prioritization analysis. The thesis proposes two indices, a "pedestrian potential index" and a "pedestrian deficiency index," which were combined, with weighting options, to generate composite block-level rankings. This conceptual model assumes that pedestrian investments should be prioritized in areas that have the greatest potential to generate pedestrian activity and that also have significant infrastructure deficiencies.

Based on the composite index results, a cluster of blocks near Technology Square was highly ranked based on both pedestrian potential and deficiency indicators. This area ranked highly for sidewalk deficiencies as well as population density and transportation mode share. The composite index prioritization results suggest that Census blocks near MARTA rail transit stations in the study area should be prioritized for pedestrian investment, particularly based on pedestrian potential indicators. The sidewalk width data results and pedestrian deficiency rankings indicate a relationship between blocks with a very high percentage of wide sidewalks and zoning, urban design and streetscape projects intended to support transit usage and walkability within the Midtown commercial district. Further, older areas outside the commercial district had the highest percentage of low-ranked sidewalk width data.

The results indicate a large amount of spatial variability across blocks within areas that ranked highly for sidewalk width deficiency. In sum, the width data and pedestrian deficiency index results indicate that the blocks with greater sidewalk deficiencies were more likely to vary spatially. Given that sidewalk repairs are the responsibility of adjacent property owners within the City of Atlanta, it is plausible that newer areas with coordinated streetscape and land-use planning are more likely to exhibit a pattern of high sidewalk quality. Additionally, the newer areas with high pedestrian activity were likely prioritized for sidewalk repair. Conversely, the sidewalk width data within the study area suggests that sidewalk quality in older neighborhoods may vary widely from block to block. Additional spatial and statistical analysis is needed in order to evaluate the extent and significance of the spatial variability of sidewalk width deficiency throughout the City of Atlanta.

This research demonstrates the application of a rank-order spatial prioritization framework for evaluating the suitability of Census blocks for sidewalk repair or replacement. This framework employs pedestrian activity, pedestrian crash, demographic, population density and sidewalk quality data to rank Census blocks using a pedestrian potential index (PPI), a pedestrian deficiency index (PDI) and a composite index ranking blocks based on both potential and deficiency variables. These analyses also demonstrate how different variable and index weightings may affect block-level prioritization results. In preparation for implementation within local jurisdictions, the indices and variables demonstrated in this framework may be weighted as desired, depending upon local policy goals and objectives, such as pedestrian safety or pedestrian travel demand. Additionally, local municipalities may be interested to develop index weightings or additional variables to prioritize sidewalk repair or reconstruction projects separately or in combination.

However, although block-level prioritization analyses may be useful for identifying areas with higher or lower pedestrian priority on a local, planning level, detailed corridor-scale condition information is necessary once projects proceed to the scoping and design stage. To operationalize this prioritization framework for use in local, regional and statewide pedestrian planning, future research should incorporate sidewalk quality, demographic and travel behavior data across larger geographic scales. The research team will also refine the sidewalk quality data analysis tools to incorporate additional data from the Sidewalk Sentry app, such as presence of obstructions, crack density and curb ramp presence (Frackelton et al., 2013).

This exploratory analysis has developed and tested a GIS-based framework to prioritize areas for pedestrian planning. These analyses suggest that built environment characteristics such as rail transit availability, neighborhood age, and urban design may be associated with high priority blocks for pedestrian prioritization. However, future analysis should test and validate these results with data at a greater geographic scope and in diverse built environment and demographic conditions.

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